Preliminary Evaluation of LTPP Continuously Reinforced Concrete (CRC) Pavement Test Sections

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LTPP

FOREWORD

This report documents analysis of the continuously reinforced concrete (CRC) pavement test sections under study in the General Pavement Studies 5 (GPS-5) experiment of the Long Term Pavement Performance Program. Limitations of the data available when this work was undertaken precluded the production of definitive findings. However, the work does show that CRC pavements can perform well.

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NOTICE

Technical Report Documentation Page

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16. Abstract

As part of the study reported here, analysis of data from the LTPP GPS-5 test sections was conducted to identify factors that influence long-term crack spacing in continuously reinforced concrete (CRC) pavements and to determine the effect of crack spacing on pavement performance. Data from the 85 test sections from the GPS-5 experiment were analyzed.

Due to the limitations of the available data and the lack of certain key data, the study was not able to produce definitive findings on factors that affect long-term crack spacing and CRC pavement performance. Lack of early-age cracking due to ambient weather conditions at the time of construction will continue to limit the value of GPS-5 to produce meaningful data on factors affecting early-age cracking. Continued monitoring of GPS-5 sites and subsequent data analysis should yield information on how CRC pavement cracking and performance changes with time, loading, and other factors. It is expected that as additional data from the GPS-5 experiment become available, it will be possible to perform more in-depth analysis of the test data to derive definitive results. Results to date, as presented in this report, do indicate that CRC pavements have the potential to provide long-term, low-maintenance service life as evidenced by the many well-performing sections in the LTPP GPS-5 experiment.

17. Key Words Concrete pavements, continuously reinforced concrete pavement, CRCP, LTPP, pavement distress, pavement performance, pavement testing, punchouts.	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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CHAPTER 1. INTRODUCTION

A continuously reinforced concrete (CRC) pavement is a portland cement concrete (PCC) pavement with continuous longitudinal steel reinforcement and no intermediate expansion or contraction joints. The continuous joint-free length of CRC pavement can extend to several miles (kilometers), with breaks provided only at structures. CRC pavements develop a transverse cracking pattern, with cracks generally spaced at about 0.6 to 1.8 m (2 to 6 ft). The cracking pattern is governed by the environmental conditions at the time of construction, the amount of steel reinforcement, and concrete strength. The steel reinforcement restrains the opening of the cracks. Also, the higher the amount of steel reinforcement used, the more closely spaced the cracks will be. Most of the cracks develop shortly after concrete placement; however, additional cracking may develop over several years as a result of continued drying shrinkage of concrete, temperature variations, and traffic loading.

A major concern with CRC pavement is punchout distress. The definition of punchout distress is the area enclosed by two closely spaced (usually less than 0.6 m [2 ft]) transverse cracks, a short longitudinal crack, and the edge of the pavement or a longitudinal joint. It also includes "Y" cracks that exhibit spalling, breakup, and faulting. The punchout distress is related to crack spacing, pavement thickness, poor foundation support, and heavy truck loadings. The repair of punchout distress typically consists of full-depth PCC patches. With time and as the number of full-depth patches increases, the pavement may be resurfaced with asphalt concrete (AC) or PCC, or it may be reconstructed. It should be noted that CRC pavements with smaller crack spacing (e.g., 0.6 m [2 ft]) do exhibit good performance provided the support condition is very good. Other distresses associated with punchouts include spalling along transverse cracks and faulting at cracks. Other leading causes of CRC failure are wide (and spalled) transverse cracks due to steel rupture 'and spalling of concrete due to steel corrosion in the presence of heavy deicing salt applications in the northern states.

Over the years, many studies have been conducted to explore the behavior and performance of CRC pavements. Many of these studies have focused on the mechanism of transverse crack development. Mechanistic procedures have been developed to predict crack spacing (e.g., CRCP-7[(1)]); however, these procedures require a fairly accurate knowledge of ambient climatic conditions and concrete's early-age properties. Other studies have focused on understanding the mechanism of punchout development. For this case also, mechanistic procedures have been proposed (e.g., Zollinger and Barenberg[(2)]). However, these mechanistic-based procedures require a fairly detailed knowledge of traffic loading (by specific axle loading) and climatic conditions (for computing curling and warping stresses and changes in the shape of the pavement as a result of temperature variation within the concrete), especially climatic (ambient) conditions during the first few days after concrete placement.

The availability of the General Pavement Studies (GPS)-5 CRC pavement test sections in the Long Term Pavement Performance (LTPP) program provides an opportunity to evaluate factors affecting the cracking of CRC pavements and to identify how the cracking pattern and other CRC pavement attributes affect CRC pavement behavior under traffic loading. As part of a Federal Highway Administration (FHWA)-sponsored project, work was undertaken to use test data from the LTPP program to study the transverse cracking pattern at the GPS-5 test sections and to evaluate the structural behavior of these sections.

As part of the LTPP program, an extensive data collection effort has been underway since about 1989. These data types are classified within the LTPP program as follows:

1. Inventory
2. Materials Testing
3. Climatic
4. Monitoring
5. Traffic
6. Seasonal

In addition, as appropriate, maintenance, rehabilitation, and construction data are also collected.

Scope of Work

The overall objective of the study reported here was to evaluate key factors affecting the development of crack spacing in CRC pavements and to determine the effect, if any, of the crack spacing on the structural response as well as the performance of the pavements. Because of lack of construction-time ambient condition data, no attempt was made to verify/validate mechanistic-based crack spacing development models such as CRCP-7 and TTICRCP. As part of the study, an attempt was also made to evaluate the structural performance of the CRC pavements using procedures developed by Professor Dan Zollinger of the Texas Transportation Institute (TTI).

Report Organization

Chapter 1 provides the background for the study. Chapter 2 provides a summary of the GPS-5 test section characteristics. Chapter 3 provides an evaluation of the crack spacing data. Chapter 4 presents an analysis of well and poorly performing test sections and chapter 5 presents a summary of findings and provides a discussion on improvements needed to be made to further advance the CRC pavement technology using LTPP data.

CHAPTER 2. GPS-5 DATA CHARACTERISTICS

The LTPP data used in this report were obtained initially from the Information Management System (IMS) during February 1996 (IMS Release 6.0 data). These data were subsequently supplemented using DataPave97, version 1 .O. The total number of GPS-5 sections available through DataPave97 was 85, with sections located in 4 climatic regions and 29 different states, as presented in tables 1 and 2. Texas has the largest number of test sections, which constitute 22 percent of all GPS-5 sections. A list of the 85 test sections is given in table 3. Each test section is also identified with a reference number (from 1 to 85) to facilitate the plotting of charts presented later. In subsequent discussion and in tables and charts, the test sections are identified by these reference numbers. At the time of DataPave97's release (data as of October 1997), 9 of the 85 sections were overlaid, as indicated in table 4. For the overlaid sections, only data for the period prior to overlay were used in this study.

The LTPP database for the GPS-5 sections consists of the following modules: inventory, environment, material testing, monitoring, and traffic. Each module contains data collected and stored at different times for different sections. The monitoring data used in the analysis are from the latest measurements available for each section for each data type.

Table 1. Distribution of GPS-5 sections by climatic regions.

Climatic Region	No. of Sections
Wet-Freeze Region	40
Wet-No Freeze Region	35
Dry-Freeze Region	6
Dry-No Freeze Region	4
Total	85

Table 2. Distribution of GPS-5 sections by state.

State	State ID	Number of GPS-5 Sections
AL	01	2
AZ	04	1
AR	05	2
CA	06	1
CT	09	1
DE	10	2
GA	13	1
ID	16	1
IL	17	8
IN	18	3
IA	19	3
MD	24	1
MI	26	1
MN	27	1
MS	28	5
MO	29	1
NE	31	1
NC	37	3
ND	38	1
OH	39	2
OK	40	3
OR	41	6
PA	42	3
SC	45	3
SD	46	3
TX	48	19
VA	51	4
WV	54	1
WI	55	2
TOTAL	29 States	85 Sections

Table 3. List of sections.

Reference No.	Section	Current Status*	Climatic Region**	Open-to-Traffic Date
1	013998		WNF	03/01/74
2	015008		WNF	12/01/77
3	047079			08/01/89
4	055803		WNF	07/01/73
5	055805		WNF	11/01/75
6	067455		DNF	12/01/71
7	095001		WF	11/01/81
8	105004		WF	06/01/77
9	105005		WF	06/01/71
10	135023		WNF	06/01/74
11	165025		DF	09/01/72
12	175020		WF	10/01/86
13	175151	7B		10/01/66
14	175843		WF	09/01/82
15	175849		WF	11/01/71
16	175854		WF	01/01/82
17	175869		WF	12/01/79
18	175908		WF	04/01/71
19	179267		WF	10/01/66
20	185022	7B	WF	01/01/72
21	185043		WF	01/01/69
22	185518	7B	WF	12/01/70
23	195042		WF	12/01/75
24	195046		WF	11/01/75
25	199116	7B	WF	08/01/72
26	245807		WF	06/01/90
27	265363		WF	12/01/76
28	275076	7B	WF	10/01/70
29	283099	7B	WNF	11/01/70
30	285006		WNF	04/01/79
31	285025		WNF	07/01/77
32	285803		WF	09/01/79
33	285805		WNF	06/01/75
34	295047		WF	07/01/72
35	315052		WF	12/01/69
36	375037		WNF	10/01/72
37	375826	7B	WF	06/01/77
38	375827		WF	03/01/73
39	385002		WF	11/01/73
40	395003		WF	09/01/88
41	395010	7B	WF	07/01/75
42	404158		WF	06/01/89
43	404166		WNF	06/01/90
44	405021		WF	10/01/87
45	415005		WNF	10/01/85

Table 3. List of sections (continued).

Reference No.	Section	Current Status*	Climatic Region**	Open-to-Traffic Date
46	415006		DF	06/01/73
47	415008		DF	06/01/72
48	415021		WNF	07/01/86
49	415022		WNF	10/01/84
50	417081		DF	09/01/88
51	421598		WF	01/01/75
52	421617	7B	WF	06/01/72
53	425020		WF	05/01/80
54	455017		WNF	03/01/79
55	455034		WNF	06/01/75
56	455035		WNF	11/01/75
57	465020		DF	08/01/73
58	465025		DF	11/01/74
59	465040		WF	07/01/63
60	483719		WNF	01/01/65
61	483779		DNF	06/01/78
62	485024		WNF	01/01/82
63	485026		WNF	06/01/88
64	485035		WNF	09/01/79
65	485154		WNF	08/01/71
66	485274		WNF	03/01/73
67	485278		DNF	06/01/75
68	485283		WNF	04/01/88
69	485284		WNF	03/01/88
70	485287		WNF	08/01/73
71	485301		WNF	02/01/82
72	4853 10		WNF	07/01/87
73	485317		WNF	04/01/82
74	485323		WF	10/01/80
75	485328		WNF	09/01/75
76	485334		WF	04/01/70
77	485335		WF	10/01/80
78	485336		WF	12/01/86
79	5 12564		WNF	02/01/69
80	515008		WNF	08/01/77
81	515009		WNF	06/01/80
82	515010		WNF	10/01/88
83	545007	taken out of study	WF	06/01/77
84	555037		WF	11/01/73
85	555040		WF	11/01/80

* 7B = GPS Experiment 7B

** WF = wet-freeze region, WNF = wet-no freeze region, DF = dry-freeze region, DNF = dry-no freeze region.

Note: Data as of October 1997.

Table 4. List of overlaid sections.

State	State ID	SHRP ID	Year Constructed	Current Status	Year Overlaid
IL	17	5151	1966	GPS-7B Section	1990
IN	18	5022	1972	GPS-7B Section	1993
IN	18	5518	1970	GPS-7B Section	1993
IA	19	9116	1972	GPS-7B Section	1989
MN	27	5076	1970	GPS-7B Section	1990
MS	28	3099	1970	GPS-7B Section	1992
NC	37	5826	1977	GPS-7B Section	1995
OH	39	5010	1975	GPS-7B Section	1990
PA	42	1617	1972	GPS-7B Section	1991

Inventory and Monitoring Data Summary

The inventory and monitoring data available for GPS-5 sections are summarized in table 5. The characteristics of the key data are discussed next.

Age

The age for the GPS-5 sections was determined as the difference between the date of the last crack survey and the traffic opening date. Based on this calculation, the age of the test sections ranged from 1 to 30 years. The age summary is given in figure 1. Also, another age calculation was made as of December 3 1, 1997, as presented in figure 2. As of December 3 1, 1997, there were 59 sections that were 15 years of age or older and 42 of these sections were 20 years of age or older. With respect to the age at the time of the last distress survey, there were 23 sections that were 20 years of age or older.

Slab Design Data

The pavement slab design data include mean slab thickness, design percent of longitudinal steel, depth to reinforcement, spacing of longitudinal and transverse reinforcing bars, and reinforcement placement method. Design parameter summaries are given in table 5 and presented in figures 3 through 7. The following observations are made:

1. Fifty sections had 203-mm-thick slabs, 18 sections had 228-mm-thick slabs, and 10 sections had 254-mm-thick slabs. Only five sections had slabs thicker than 270 mm and only three sections had slabs thinner than 200 mm. This represents a very biased sample.

Table 5. GPS-5 data summary.

Section No.	Section ID	Current Status	Climatic Region	Manual Survey Date	Manual Total Trans. Crack No.	Manual Total High Severity Trans. Crack No.	Manual Average Crack Spacing, m	PADIAS Survey Date	PADIAS Total Trans. Crack No.	PADIAS Total High Severity Trans. Crack No.	PADIAS Average Crack Spacing, m	Least Average Crack Spacing from Manual and PADIAS surveys, m	Date Tested for Least Average Crack Spacing	Open-to-Traffic Date	Age as Tested, years	Ageasof 1/1/98, years	Total Punchouts and Patches
1	01-3998		WN					04/16/90	61	0	2.50	2.50	04/16/90	03/01/74	16	23	3
2	01-5008		WN					02112190	118	0	1.29	1.29	02/12/90	12/01/77	13	20	0
3	04-7079		DN					01/15/91	83	0	1.84	1.84	01/15/91	08/01/89	2	8	0
4	05-5803		WN	11/29/94	159	0	0.96	02/27/91	153	0	1.00	0.96	11/29/94	07/01/73	21	24	0
5	05-5805		WN	11/28/94	213	0	0.7;	11/14/89	123	0	1.24	0.72	11/28/94	11/01/75	19	22	0
6	06-7455		DN	12/17/91	221	0	0.69					0.69	12/17/91	12/01/71	20	26	0
7	09-5001		WF	04/09/96	115	1	1.3:	09/04/90	99	0	1.54	1.33	04/09/96	11101181	15	16	0
8	10-5004		WF	03/16/93	113	0	1.3!	03/21/91	52	0	2.93	1.35	03/16/93	06/01/77	16	20	0
9	10-5005		WF					03/21/91	99	0	1.54	1.54	03/21/91	06/01/71	20	26	0
10	13-5023		WN	10/27/94	80	0	1.9'	02/09/91	66	0	2.31	1.91	10/27/94	06/01/74	20	23	0
11	16-5025		DF	08/01/95	182	0	0.84	09/20/89	121	0	1.26	0.84	08/01/95	09/01/72	23	25	2
12	17-5020		WF	07/15/91	19	0	8.0:	05/13/91	134	0	1.14	1.14	05/13/91	10/01/86	5	11	0
13	17-5151	7B/1990	WF											10/01/66		31	0
14	17-5843		WF	08/02/88	76	0	2.0	10/15/90	64	1	2.38	2.01	08/02/88	09101182	6	15	0
15	17-5849		WF	08/04/88	215	0	0.7'	06/24/89	231	0	0.66	0.66	06/24/89	11/01/71	18	26	0
16	17-5854		WF	08/04/88	125	0	1.2:	06/24/89	127	0	1.20	1.20	06/24/89	01/01/82	7	15	0
17	17-5869		WF	08/04/88	107	0	1.4:	06/24/89	96	0	1.59	1.43	08/04/88	12/01/79	9	18	0
18	17-5908		WF	03/24/93	86	0	1.7	05/10/91	82	0	1.86	1.77	03/24/93	04/01/71	221	26	0
19	17-9267		WF	07/07/89	212	0	0.7:	05/07/90	184	0	0.83	0.72	07107189	10/01/66	23	31	0
20	18-5022	7B/1993	WF	07/13/88	77	0	1.9	09/25/89	75	2	2.03	1.98	07/13/88	01/01/72	16	25	0
21	18-5043		WF					05/09/91	119	0	1.28	1.28	05/09/91	01/01/69	22	28	0
22	18-5518	7B/1993	WF	12/01/89	165	0	0.9:					0.92	12/01/89	12/01/70	19	27	0
23	19-5042		WF	09/07/89	140	0	1.0!	05/18/91	132	0	1.16	1.09	09/07/89	12/01/75	14	22	0
24	IQ-5046		WF	08/30/94	81	0	1.8	05/18/91	15	1	10.17)	1.88	08130194	11/01/75	19	22	2
25	19-9116	7B/1989	WF	07/28/89	210	0	0.7:					0.73	07/28/89	08/01/72	17	25	0
26	24-5807		WF					10/11/89	13	0	11.73		10/11/89	06/01/90	1	7	0
27	26-5383		WF	05/21/93	162	0	0.9	07/18/90	67	0	2.28	0.94	05/21/93	12/01/76	171	21	3
28	27-5076	7B/1990	WF					06/09/89	227	0	0.67	0.67	06/09/89	10/01/70	19	27	0
29	28-3099	7B/1992	WN	03/07/91	2381	0	0.6	02/14/91		0		0.64	03/07/91	11/01/70	21	27	0
30	28-5006		WN	03/04/91	172	0	0.8	03/03/91	132	0	1.16	0.89	03/04/91	04/01/79	12	18	0
31	28-5025		WN	07/13/93	129	0	1.1	01/14/91	116	0	1.31	1.18	07/13/93	07/01/77	16	20	0
32	28-5803		WF	11/29/95	124	0	1.2	01110/9(	80	0	1.91	1.23	11/29/95	09/01/79	16	18	3
33	28-5805		WN	03/07/91	154	0	0.9	01/15/91	143	0	1.07	0.99	03/07/91	06/01/75	16	22	0
34	29-5047		WF	08/19/88	99	0	1.5	06/20/9(	88	0	1.73	1.54	08/19/88	07/01/72	16	25	0
35	31-5052		WF	04/19/93	118	0	1.2	05/15/89	127	0	1.20	1.20	05/15/89	12/01/69	20	28	0
36	37-5037		WN	01/29/96	120	0	1.2	03/10/91	96	0	1.59	1.27	01/29/96	10/01/72	24	25	0
37	37-5826	7B/1995	WF					03/11/91	107	0	1.43	1.43	03/11/91	06/01/77	14	20	0
38	37-5827		WF	12/17/96	82	0	1.8	03/19/91	66	0	2.31	1.86	12/17/96	03/01/73	23	24	1
39	38-5002		WF					12/06/9(	228	0	0.67	0.67	12/06/90	11/01/73	17	24	0
40	39-5003		WF	07/13/94	161	0	0.9	10/03/9(		0		0.95	07/13/94	09/01/88	6	9	0
41	39-5010	7B/1990	WF	11/29/88	141	0	1.0					1.08	11/29/88	07/01/75	13	22	0
42	40-4158		WN	11/04/92	90	0	1.6	03/14/91	67	0	2.281	1.69	11/04/92	06/01/89	3	8	0
43	40-4166		WN	11/01/94	144	0	1.0	10/30/9(	26	0	5.67)	1.06	11/01/94	06/01/90	4	7	0

Table 5. GPS-5 data summary (continued).

Section No.	Section ID	Current Status	Climatic Region	Manual Survey Date	Manual Total Trans. Crack No.	Manual Total High Severity Trans. Crack No.	Manual Average Crack Spacing, m	PADIAS Survey Date	PADIAS Total Trans. Crack No.	PADIAS Total High Severity Trans. Crack No.	PADIAS Average Crack Spacing, m	Least Average Crack Spacing from Manual and PADIAS surveys, m	Date Tested for Least Average Crack Spacing	Open-to-Traffic Date	Age as Tested, years	Age as of 1/1/98, years	Total Punchouts and
44	40-5021		WF	11/01/94	132	0	1.16	10/30/90	83	0	1.84	1.16	11/01/94	10/01/87	7	10	
45	41-5005		DF					09/18/89	33	0	4.62		09/18/89	10/01/85	4	12	0
46	41-5006		DF	04/30/96	137	16	1.11	09/18/89	112	67	1.36	1.11	04/30/96	06/01/73	23	24	0
47	41-5008		DF	04/29/96	166	0	0.92	09/18/89	178	0	0.86	0.86	09/18/89	06/01/72	17	25	0
46	41-5021		WN	06/27/94	226	1	0.67	07/26/89	148	0	1.03	0.67	06/27/94	07/01/86	8	11	0
49	41-5022		WN	05/23/96	137	0	1.11	09/08/89	93	0	1.64	1.11	05/23/96	10/01/84	12	13	0
50	41-7081		DF					09/18/89	[illegible]	0				09/01/88		9	0
51	42-1596		WF	07/27/95	82	0	1.86	03/25/90	79	0	1.93	1.86	07/27/95	01/01/75	20	22	2
52	42-1617	7B/1991	WF											06/01/72		25	0
53	42-5020		WF					09/12/90	104	0	1.47	1.47	09/12/90	05/01/80	10	17	0
54	45-5017		WN	06/07/93	101	0	1.51	03/05/91	88	0	1.73	1.51	06/07/93	03/01/79	14	18	0
55	45-5034		WN	03/17/92	101	0	1.51	03/05/91	100	0	1.53	1.51	03/17/92	06/01/75	17	22	0
56	45-5035		WN	06/08/93	224	0	0.68	06/05/90	160	0	0.95	0.68	06/08/93	11/01/75	18	22	1
57	46-5020		DF	10/05/93	249	0	0.61	12/11/90	226	0	0.67	0.61	10/05/93	08/01/73	20	24	0
58	46-5025		DF	05/02/89	246	0	0.62	12/17/90	236	0	0.65	0.62	05/02/89	11/01/74	15	23	0
59	46-5040		WF					12/15/90	330	0	0.46	0.46	12/15/90	07/01/63	27	34	0
60	48-3719		WN	06/08/95	125	1	1.22	02/27/91	95	1	1.61	1.22	06/08/95	01/01/65	30	32	0
61	48-3779		DN	11/07/95	131	0	1.16	09/11/90	112	0	1.36	1.16	11/07/95	06/01/78	17	19	0
62	48-5024		WN	07/10/95	129	2	1.18	10/12/90	83	8	1.84	1.18	07/10/95	01/01/82	13	15	0
63	48-5026		WN	06/06/95	144	0	1.06	02/26/91	94	0	1.62	1.06	06/06/95	06/01/88	7	9	0
64	48-5035		WN	06/30/95	139	0	1.10	10/27/90	86	0	1.77	1.10	06/30/95	09/01/79	16	18	0
65	48-5154		WN	07/10/95	108	0	1.41	10/12/90	94	0	1.62	1.41	07/10/95	08/01/71	24	26	0
66	48-5274		WN	02/11/97	75	0	2.03	10/29/90	60	0	2.54	2.03	02/11/97	03/01/73	24	24	0
67	48-5278		DN	06/05/95	176	0	0.87	01/24/91	156	0	0.98	0.87	06/05/95	06/01/75	20	22	0
68	48-5283		WN	02/13/97	117	0	1.30	10/27/90	45	0	3.39	1.30	02/13/97	04/01/88	9	9	0
69	48-5284		WN	02/13/97	83	0	1.84	10/27/90	21	0	7.26	1.84	02/13/97	03/01/88	9	9	1
70	48-5287		WN	02/14/97	143	0	1.07	10/27/90	101	0	1.51	1.07	02/14/97	08/01/73	24	24	2
71	48-5301		WN	02/13/97	123	6	1.24	10/27/90	89	0	1.71	1.24	02/13/97	02/01/82	15	15	1
72	48-5310		WN	02/11/97	86	0	1.77	03/11/91	55	0	2.77	1.77	02/11/97	07/01/87	10	10	6
73	48-5317		WN	02/11/97	74	0	2.06	03/21/89	58	0	2.63	2.06	02/11/97	04/01/82	15	15	2
74	48-5323		WF	08/10/95	235	1	0.65	04/24/89	190	0	0.80	0.65	08/10/95	10/01/80	15	17	23
75	48-5328		WN	08/05/93	133	0	1.15	03/11/91	104	0	1.47	1.15	08/05/93	09/01/75	18	22	1
76	48-5334		WF	08/11/95	219	0	0.70	04/25/89	215	0	0.71	0.70	08/11/95	04/01/70	25	27	0
77	48-5335		WF	08/10/95	209	0	0.73	04/24/89	184	0	0.83	0.73	08/10/95	10/01/80	15	17	6
78	48-5336		WF	08/08/95	162	0	0.94	01/11/90	87	0	1.75	0.94	08/08/95	12/01/86	9	11	0
79	51-2564		WN					03/20/91	166	0	0.92	0.92	03/20/91	02/01/69	22	28	0
80	51-5008		WN					03/20/91	156	0	0.98	0.98	03/20/91	08/01/77	14	20	0
81	51-5009		WN	12/18/96	128	2	1.19	03/20/91	79	0	1.93	1.19	12/18/96	06/01/80	16	17	4
82	51-5010		WN					03/20/91	25	0	6.10		03/20/91	10/01/88	3	9	0
83	54-5007		WF					05/01/91	212	2	0.72	0.72	05/01/91	06/01/77	14	20	n/a
84	55-5037		WF	08/24/88	85	0	1.79	10/19/90	109	0	1.40	1.40	10/19/90	11/01/73	17	24	0
85	55-5040		WF	11/07/94	118	0	1.29	09/12/89	90	0	1.69	1.29	11/07/94	11/01/80	14	17	0

Table 5. GPS-5 data summary (continued).

Section No.	Section ID	IRI Date	Avg IRI, m/km	Design % Long. Steel	Depth Reinforcement, mm	Long. Bar Spacing, mm	Trans. Bar Spacing, mm	Reinforcement Place Method	Mean Slab Thick, mm	Average Compressive Strength, MPa	Average Split Tensile Strength, MPa	E Lab Tested, GPa	E Slab Backcalc., GPa	Base Thickness, mm	E Base Backcalc., GPa	Base Material Type	Date Modulus Evaluated
1	01-3998	05/04/90	1.32	0.59	76	168	782	Chairs	203	57.7	6.2	46.3	58.0	152	8.4	SC	09/13/90
2	01-5008	12/10/90	0.94	0.68	114	185	985	Chairs	229				55.8	152	8.1	ACM	09/17/90
3	04-7079	03/23/90	1.03	0.57	114	152	884	Chairs	229		4.7	27.2		102		ACM	
4	05-5803	09/23/94	1.45	0.61	102	102	406	Chairs	203					1521		ACM	
5	05-5805	09123194	1.32	0.61	89	160	762	Chairs	203				53.7	178	7.8	ACM	06/07/93
6	06-7455	05/01/91	1.23	0.56	102	165	1524	Chairs	213		4.8	32.0	54.0	137	7.8	CAM	12/01/89
7	09-5001	04/12/96	1.80	0.60	102	160	864	Chairs	203	629	4.6	36.7	44.9	254	6.5	G	04/09/96
8	Io-5004	10/17/93	1.18	0.60	97	152		Chairs	229	42.21	4.21	21.9	30.4	102	4.4	SC	03/16/93
9	IO-5005	06/19/91	1.07	0.60	97	152		Chairs	203	34.51	4.8	18.6	38.8	1021	5.3	SC	07/26/91
10	13-5023	05/17/94	1.28	0.60	99	152		Mech	216	49.9	5.3	33.2	43.2	152	6.3	CAM	03/15/95
11	16-5025	09/12/94	2.39	0.61	64	229		Other	203		3.5	29.6	32.0	102	4.6	CAM	08/01/95
12	17-5020	03/06/91	17.7	0.73	76	193	1219	Chairs	203	48.1	4.7	23.6	37.4	102	5.4	PAM	11/01/90
13	17-5151	03/11195	1.15	0.69	76	165	1219	Chairs	203		4.1	33.8		102		G	
14	17-5843	06/12/90	1.18	0.71	58	185	1219	Mech	254	65.1	4.5	40.7	28.9	102	4.2	CAM	07/30/90
15	17-5849	03/12/90	1.58	0.70				Other	178	55.8	4.6	27.6	48.7	102	7.1	ACM	11 II 3/89
16	17-5854	04/09/90	2.13	0.61	94	127		Mech	254	55.9	4.6	34.3	53.6	102	7.8	CAM	05/02/90
17	17-5869	04/10/90	170	0.72	a9	147		Mech	229	64.6	5.4	40.3	29.1	102	4.2	LT	05/02/90
18	17.5908	10/06/92	2.021	0.571	76	1651	1219	Chairs	203	52.5	3.5	23.1	42.5	102	6.2	ACM	03/24/93
19	17-9267	04/08/90	1.10		76	165	1219	Chairs	203	60.7	4.7	42.9	43.3	102	6.3	ACM	09/19/90
20	18-5022	03/18/95	0.94	0.60				Mech	229	50.9	3.7	40.5	45.3	102	6.6	ACM	07/21/90
21	18-5043	06/13/91	2.41	0.60				Chairs	185	54.8		35.8	37.6	203	5.5	G	05/17/90
22	18-5518	07/25/90	1.32	0.61				Chairs	229	44.9	4.9	33.2	38.1	152	5.5	G	04/30/92
23	19-5042	06/19/90	1.70	0.65	89	216		Mech	203	56.2	4.3	30.0	50.3	102	7.3	ACM	04/18/90
24	19-5046	09/16/94	1.55	0.65	89	216		Mech	203	51.71		31.21	45.51	1021	6.6	CAM	08/30/94
25	19-9116	04/08/90	0.84	0.65	76	216		Mech	203	48.2	3.4	33.8	45.7	102	6.6	ACM	07/10/89
26	24-5807	12/04/95	1.48	0.53	109	241	1372	Chairs	229	40.7	4.5	30.6	51.0	152	7.4	CAM	04/24/89
27	28-5363	04/22/93	1.83	0.70	102	165		Other	229	52.2		30.1	37.1	102	5.4	G	06/25/90
28	27-5076	05/22/90	0.77					Other	229	62.2	5.2	37.2	42.5	152	6.2	G	07/02/90
29	28-3099	10/09/91	1.47	0.611	102	165	1067	Chairs	203	68.61	5.6	39.1	32.8	152	4.8	SC	10/10/91
30	28-5006	12/05/90	1.45	0.59	97	165	914	Chairs	203	64.8	5.2	34.6	32.0	152	4.6	CAM	10/08/90
31	28-5025	08/01/95	1.41	0.59	97	165	914	Chairs	203				47.8	102	6.9	ACM	10/31/94
32	28-5803	01/27/94	1.55	0.59	97	165	914	Mech	203	53.7	4.9	31.5	28.5	152	4.1	ACM	11/29/95
33	28-5805	06/04/90	1.30	0.59	76	165	762	Chairs	203				70.2	102	10.2	ACM	11/23/92
34	29-5047	03/19/90	1.59	0.60	89	152	1219	BTW	203	47.0	5.0	34.8	55.5	102	8	G	10/24/89
35	31-5052	11/20/89	1.05	0.75	64	152	914	Chairs	203	40.1	4.2	25.7	62.2	76	9	SC	08/11/89
36	37-5037	11/16/94	1.07	0.60	102	762	305	Chairs	203	55.6	4.9	21.4	34.6	102	5	G	01/29/96
37	37-5826	03/26/91	1.22	0.65	76	152	762	Other	203	55.5	4.7	28.4	40.7	38	5.9	ACM	1 0/I 6/89
38	37-5827	04/25/96	0.99	0.60	76	152	762	Other	203	44.9	3.7	22.2	38.8	102	5.6	G	12/17/96
39	38-5002	10/25/89	1.26	0.60	102	165	1219	Mech	203				41.5	51	6	ACM	08/28/90
40	39-5003	04/04/94	1.15	0.96	102	160	762	Chairs	254	51.7	5.4	26.2	41.2	102	6	ACM	07/13/94
41	39-5010	09/28/89	1.84					Other	203					102		CAM	
42	40-4158	08/28/91	1.03	0.61	1271	185	1118	Mech	262				40.01	114	5.8	ACM	05/19/93
43	40-4166	11/17/93	0.95	0.721	1271	185	1118	Mech	259	56.3	4.51	33.4	45.3	102	6.6	CAM	05/28/93

Table 5. GPS-5 data summary (continued).

Section No.	Section ID	IRI Date	Avg IRI, m/km	Design % Long. Steel	Depth Reinfor-cement, mm	Long. Bar Spacing, mm	Trans. Bar Spacing, mm	Reinfor-cement Place Method	Mean Slab Thick, mm	Average Compressive Strength, MPa	Average Split Tensile Strength, MPa	E Lab Tested, GPa	E Slab Backcalc.. GPa	Base Thickness, mm	E Base Backcalc.. GPa	Base Material Type	Date Modulus Evaluated
44	40-5021	09/16/93	0.94	0.59	114	147	1118	Mech	229				48.7	89	7.1	ACM	05/18/93
45	41-5005	11/17/89	1.32	0.51	122	147	1524	Chairs	279		5.e	31.5	60.4	165	8.8	LC	1 OH 8/89
46	41-5008	10/20/89	1.43	0.51	102	165	1524	Chairs	203		3.E	28.4	73.7	152	10.7	CAM	04/30/96
47	41-50(							rs	203		3.3	31.:	37.8	102	5.5	CAM	08/24/89
48	41-5021	03/31/93	1.091	0.51	0.511 102	1091 165	1651 1524	Mech	274		5.9	22.9	41.5	229	6	CAM	06/27/94
49	41-5022	11/18/89	0.94	0.51	76	122	1524	Chairs	305		5.5	24.:	33.3	508	4.8	G	05/23/96
50	41-7081	05/20/97	0.82	0.70	109	165	914	Chairs	254		5.1	26.0	51.0	203	7.4	LC	04/19/96
51	42-1598	11/08/95	1.81	0.65	a9	147	864	Chairs	229	65.0	4.4	43.1	36.9	203	5.3	G	07/27/95
52	42-1617	11/10/95	0.84	0.64	89	152	664	Chairs	229	41.3	5.5	40.0	38.2	203	5.5	G	04/25/90
53	42-5020	05/16/90	1.81	0.65	89	203	864	Chairs	229	48.6	4.2	43.t	59.3	152	8.6	G	04/24/90
54	45-5017	04/29/92	2.05	0.57	99	152	762	Chairs	229	44.8	5.9	20.8	35.2	152	5.1	CAM	08/31/92
55	45-5034	04/29/92	1.42	0.64	89	152	762	Chairs	203	47.4	3.8	21.5	36.0	127	5.2	CT	09/02/92
56	45-5035	04/10/94	1.22	0.64	89	152	762	Chairs	203	50.7	3.6	24.:	40.8	127	5.9	CT	10/26/92
57	46-5020	06/16/93	0.97	0.59	64	165	1219	Chairs	203	54.0	4.5	27.f	34.5	51	5	ACM	10/05/93
58	46-5025	11/18/89	1.31	0.59	64	165	1219	Chairs	203	56.8	5.a	29.1	45.6	76	6.6	G	06/08/89
59	46-5040	11/13/89	1.99	0.65	64	152	1118	Chairs	203	73.4	5.6	33.2	39.4	76	5.7	G	10/25/91
60	48-3719	02/03/95	2.29	0.51	102	191	610	Chairs	203	51.9	4.3	44.1	48.5	102	6.7	CAM	01/04/95
61	48-3779	10/13/94	2.23	0.51	102	191	914	Chairs	203				35.5	51	5.2	ACM	11/16/94
62	48-5024	01/31/95	2.32	0.60	127	185	914	Chairs	254				65.1	102	9.4	ACM	10/06/93
63	48-5026	02/01/95	1.72	0.56	127	198	610	Mech	254	62.7	5.7	37.i	48.7	152	7.1	CAM	03/06/90
64	48-5035	12/07/94	1.86	0.61	102	160	914	Chairs	203				36.0	152	5.2	ACM	08/23/93
65	48-5154	01/30/95	1.66	0.52	102	191	914	Chairs	203				66.9	102	9.7	ACM	12/03/91
66	48-5274	12/08/94	1.66	0.51	102	191	914	Chairs	203				38.6	102	5.3	ACM	08/19/93
67	48-5278	11/16/94	1.67	0.61	76	216	914	Chairs	152				59.9	102	8.7	ACM	01/27/95
68	48-5283	12/07/94	1.18	0.52	127	216	610	Chairs	254				38.6	51	5.6	ACM	08/25/93
69	48-5284	12/07/94	2.43	0.50	140	203	610	Chairs	279				39.0	51	5.7	ACM	08124193
70	48-5287	12/06/94	2.02	0.51	102	191	914	Chairs	203				29.0	102	4.2	ACM	02/12/96
71	48-5301	12/05/94	1.69	0.60	127	185	914	Chairs	254				46.6	51	6.8	ACM	08/20/93
72	48-5310	12/06/94	2.01	0.50	140	203	610	Chairs	279				34.6	102	5	ACM	08/30/93
73	48-5317	12/12/94	2.34	0.51	102	191	914	Chairs	203				51.7	51	7.5	ACM	08/18/93
74	48-5323	11/22/94	1.79	0.61	114	203	914	Mech	229	57.0	4.1	29.3	38.1	152	5.5	ACM	01/23/95
75	48-5328	04/21/93	1.59	0.61	102	160	914	Chairs	206				45.1	109	6.5	ACM	08/31/93
76	48-5334	01/12/95	1.10	0.51	97	191	762	Other	203	47.4	4.8	35.c	37.5	102	5.4	ACM	01/18/95
77	48-5335	11/22/94	2.01	0.61	114	203	914	Mech	229	63.9	4.9	35.0	28.9	152	4.2	ACM	01/20/95
78	48-5336	11/21/94	1.42	0.61	114	203	914	Mech	229				43.9	152	6.4	ACM	01/25/95
79	51-2564	06/21/91	0.97	0.60	89	152		Mech	203	51.6	4.4	24.8	29.6	152	4.3	SC	02/27/90
80	51-5008	06/21/91	2.07	0.60	89	152		Mech	203	45.2	5.0	25.1	36.3	127	5.3	SC	02/28/90
81	51-5009	12/13/95	2.17	0.60	89	152		Mech	203	50.2	4.3	25.3	53.7	152	7.8	CAM	04/30/90
82	51-5010	12/07/89	1.55	0.65	102	191		Mech	229	39.0	4.6	31.c	53.3	203	7.7	CAM	05/01/90
83	54-5007	11/15/91	2.35	0.65	76			Chairs	203	57.7	5.2	21.9	24.0	152	3.5	ACM	06/17/91
84	55-5037	09/17/95	1.14	0.61	76	229		Mech	203	59.4	5.8	34.6	49.4	152	7.2	G	08/21/90
85	55-5040	07/14/94	2.39	0.65	76	216		Other	203	54.9	5.4	42.7	43.3	152	6.3	G	11/07/94

Table 5. GPS-5 data summary (continued).

Section No.	Section ID	Bond	k-value Backcalc., MPa/mm	AASHTO Soil Classif.	Soil Type Coarse/Fine	Outside Shoulder Type	Average Annual Freeze index, degrees C	Annual pracip., degrees C	Average Daily Temp. Range.	KESAL 18k Total
1	01-3998	1.01	91	A-2-4	C	PCC (JPCP)	3	13.6		691
2	01-5008	1.0	44	A-5	F	PCC (JRCP)	41	1345	13.8	884
3	04-7079			A-6	F	PCC (JPCP)	0			70
4	05-5803			A-4	F	AC	69	1336	11.9	182
5	05-5805	1.0	159		-	PCC (JRCP)	73	1298	11.9	272:
6	06-7455	1.0	42	A-6	C	AC	1	270	15.1	1564
7	09-5001	1.0	33	A-2-4			397	12431	12.21	
8	10-5004	0.0	36	A-1-b	C	AC	197	10941	10.51	4031
9	10-5005	1.0	78	A-4	F	PCC (JRCP)	125	1160	11.6	597
10	13-5023	1.0	69	A-3	C	AC	2	1266	11.2	2133
11	16-5025	1.0	103	A-1-a	C	AC	543	370	17.0	1450
12	17-5020	0.0	48	A-6	F	PCC (JPCP)	196	1036	12.1	32
13	17-5151			A-4	C	PCC (JRCP)				1745
14	17-5843	1.0	57	A-6	F	AC	548	820	11.4	489
15	17-5849	1.0	65	A-4	F	AC	468	1000	11.8	1025
16	17-5854	0.0	51	A-6	F	AC	462	968	11.9	70
17	17-5869	1.0	78	A-4	F	AC	506	979	11.6	113
18	17-5908	1.0	58	A-1-b	C	AC	255	58	12.4	246
19	17-9267	1.0	82	A-1-b	C	PCC (JRCP)	565	925	10.7	1631'
20	18-5022	1.0	73	A-4	F	AC	393	1055	11.6	6311:
21	185043	1.01	70	A-7-6	C	AC	202 442	1160 55	113 111	32
22	18-5518	1.0	73	A-2-4	-					6802
23	19-5042	1.0	57	A-4	F	AC	823	828	12.0	592
24	19-5046	1.0	83	A-2-4	C	AC	814	820	11.9	845
25	19-9116	1.0	58	A-6	F	AC	933	821	11.4	689
26	24-5807	1.0	69	A-4	F	PCC (JPCP)	131	1075	11.0	
27	26-5363	1.01	59	A-2-4	C	AC	483	860	10.6	398
28	27-5076	1.0	46	A-4	F	AC	943	798	11.1	548
29	28-3099	1.0	44	A-7-6	F	PCC (JRCP)	18	1570	14.0	249
30	28-5006	1.0	120	A-7-6	F	AC	571	1387	12.8	236%
31	26-5025	0.0	103	A-2-4	C	PCC (JRCP)	24	15611	13.51	150
32	28-5803	1.0	61	A-2-4	C	AC	971	1441	12.7	511
33	28-5805	1.01	57	A-3	C	AC	4	1055	10.5	1114
34	29-5047	1.0	42	A-6	F	PCC (JRCP)	305	958	12.31	539
35	31-5052	1.0	43	A-7-6	F	AC	574	7341	11.51	526
36	37-5037	1.0	55	A-5	C	AC	83	...	13.4	1236
37	37-5826	1.0	34	A-4	F	AC		1175		
38	37-5827	1.0	31	A-1-b	C	AC	[illegible]	1150 1163	117 113	823 311
39	38-5002	1.0	32	A-7-6	F	PCC (JPCP)	1299	510	12.0	497
40	39-5003	1.0	125	A-4	F	PCC (JPCP)	364	952	10.8	82
41	39-5010			A-4	F	AC	429	980	12.6	227
42	40-4158	1.0	84	A-2-4	C	PCC (JPCP)	80	1072	13.6	922
43	40-4166	1.0	106	A-6	F	PCC (JPCP)	55	1686	12.3	10481

Table 5. GPS-5 data summary (continued).

Section No..	Section ID	Bond	k-value Backcalc., MPa/mm	AASHTO Soil Classif.	Soil Type Coarse/Fine	Outside Shoulder Type	Average Annual Freeze Index, degrees C days	Annual precip.. mm	Average Daily Temp. Range, degrees C	KESAL_ 18k Total
44	40-5021	1.c	75	A-6	F	PCC (JPCP)	141	1065	12.9	673
45	41-5005	0.C	8 :7	A-6	C	AC	1:	377'	11.7	110%
48	41-5006	1.C	38	A-7-6	F	AC	21(	426	13.5	13754
47	41-5008	I.C	145	A-2-6	C	AC	21;	42B	13.4	995
48	41-5021	1.C	7'1	A-4	F	AC	2i	1117	12.7	1158
49	41-5022	1.C	50	A-6	F	AC	26	112fi	12.3	1692
50	41-7081	0.C	97	A-1-b	C	AC	124	176	11.8	146
51	42-1598	1.C	107	A-2-4	C	PCC (JRCP)	24(	1033	10.5	2282
52	42-1617	1.C	99		C	AC	20;	1132	11.3	638
53	42-5020	1.C	5'1	A-4	F	AC	216	1116	11.5	5111
54	45-5017	1.C	164	A-2-4	C	AC	2(	1175	12.9	829
55	45-5034	1.C	1210	A-2-4	C	AC	If	1147	13.3	497:
56	45-5035	0.C	74	A-2-4	C	AC	1!	1138	13.0	603
57	46-5020	1.C	125	A-2-4	C	AC	62(	451	15.8	94;
58	46-5025	1.C	39	A-7-6	F	AC	576	4oc)	15.0	55
59	46-5040	1.C	39	A-6	F	AC	91(	606	12.5	134:
60	48-3719	1.C	4 ,7	A-7-6	F	PCC (JRCP)		1518	10.5	919
61	48-3779	1.C	48			AC	11	264	18.1	932
62	48-5024	1.C	85	A-2-6	C	PCC (JPCP)	If	999	14.1	152:
63	48-5026	1.C	53	A-7-6	F	PCC (JPCP)	I	1123	9.8	23
64	48-5035	1.C	209			PCC (JPCP)	3!	934	12.0	949:
65	48-5154	1.C	130	A-2-7	C	AC	(	953	12.2	10317
66	48-5274	1.C	75	A-2-7	C	AC	3(	861	12.4	592
67	48-5278	1.C	168	A-2-4	C	AC	3:	404	15.2	118
68	48-5283	1.C	10:2	A-2-6	C	PCC (JPCP)	4(	965	12.5	155'
69	48-5284	1.C	84	A-2-6	C	PCC (JPCP)	4(	969	12.8	101
70	48-5287	0.C	66	A-5	F	AC	3 i	a84	12.8	4531
71	48-5301	1.C	129	A-6	F	PCC (JPCP)	5:	838	12.9	176
72	48-5310	1.C	95	A-7-6	F	PCC (JRCP)	44	946	13.8	223
73	48-5317	0.C	4 ,7	A-2-7	C	PCC (JRCP)	3(	888	12.5	4426
74	48-5323	1.c	8 1	A 6	F	PCC (JPCP)	13	566	15.3	974
75	48-5328	1.C	8:2	A-5	F	PCC (JRCP)	5!	859	12.7	729:
78	48-5334	1.c	10:2	A-4	F	PCC (JRCP)	13:	574	15.0	1175
77	48-5335	1.C	8'1	A-6	F	PCC (JPCP)	13(	584	15.3	891
78	48-5336	1.C	79	A-7-5	F	PCC (JPCP)	13!	526	15.9	148(
79	51-2564	0.C	90	A-4	F	AC	4!	1178	10.2	1175
80	51-5008	0.C	85	A-4	F	AC	4(	1159	9.7	1050
81	51-5009	0.C	87	A-2-4	C	AC	7(	1077	12.2	220i
82	51-5010	0.C	I0'1	A-7-6	F	PCC (JPCP)	71	1092	12.2	381
83	54-5007	0.C	50	A-4	F	AC	31:	1215	13.0	175:
84	55-5037	1.C	718	A-1-b	C	AC	108(	811	12.9	2823
85	55-5040	1.C	49	A-7-6	F	PCC (JPCP)	52:	845	9.3	911

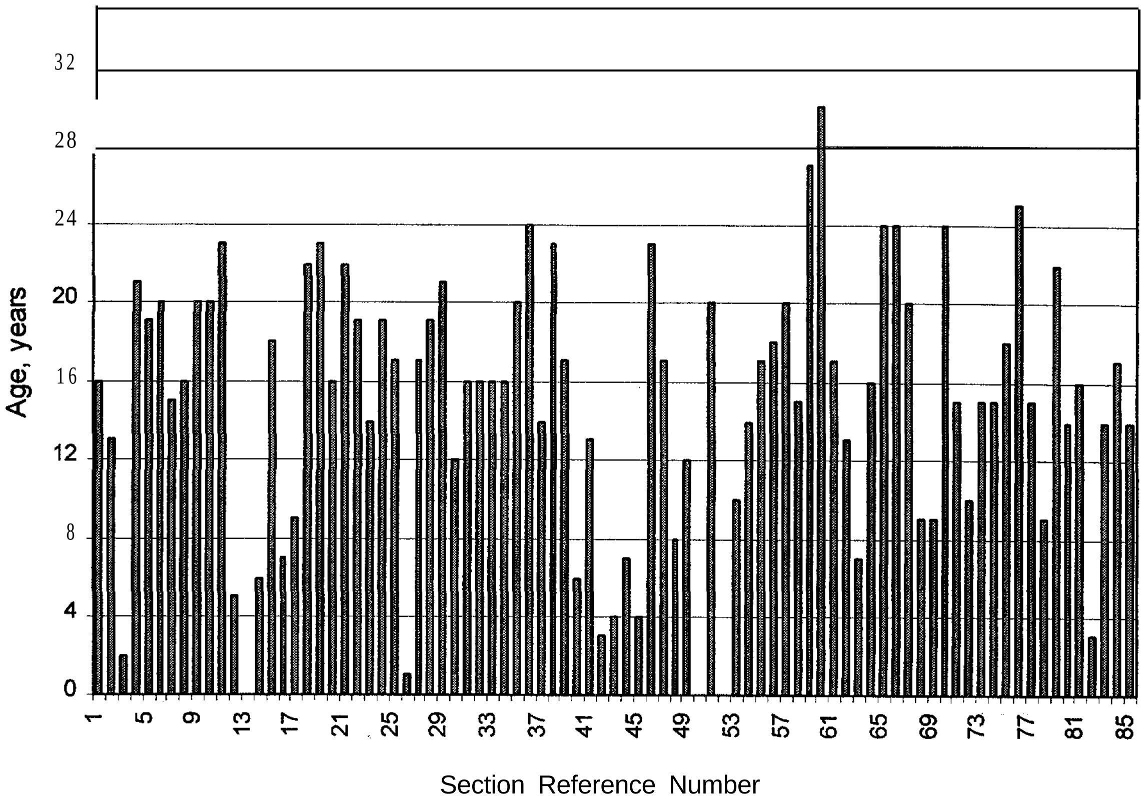

Figure 1. Age as of latest distress survey.

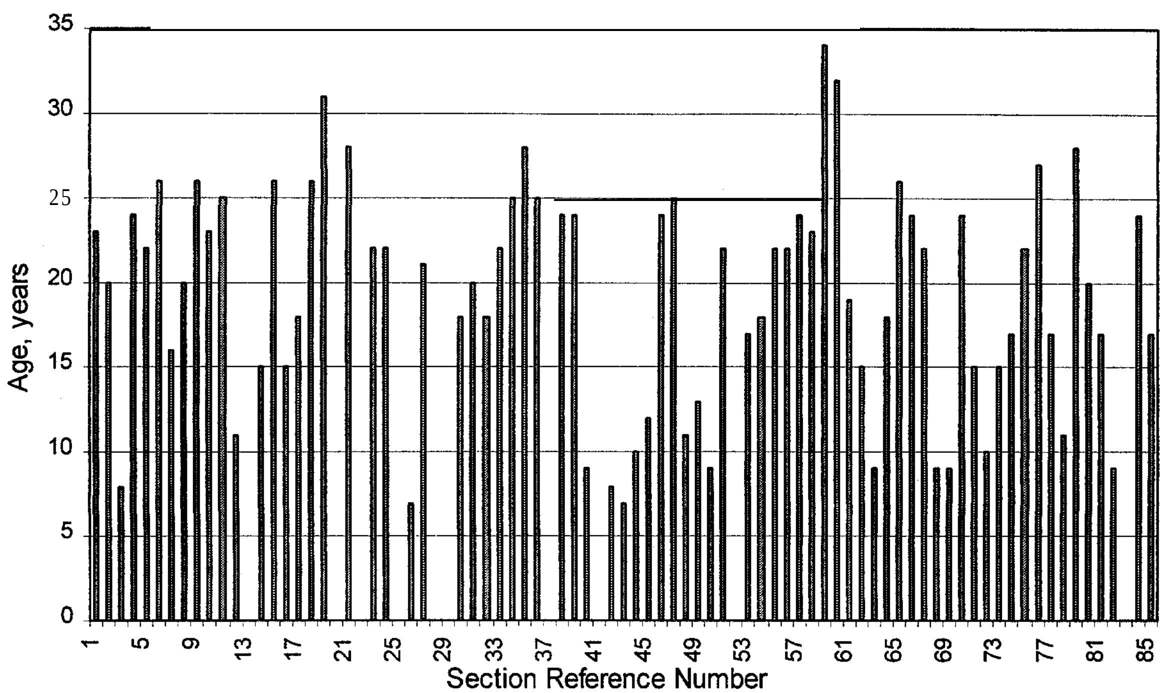

Figure 2. Age as of December 31, 1997.

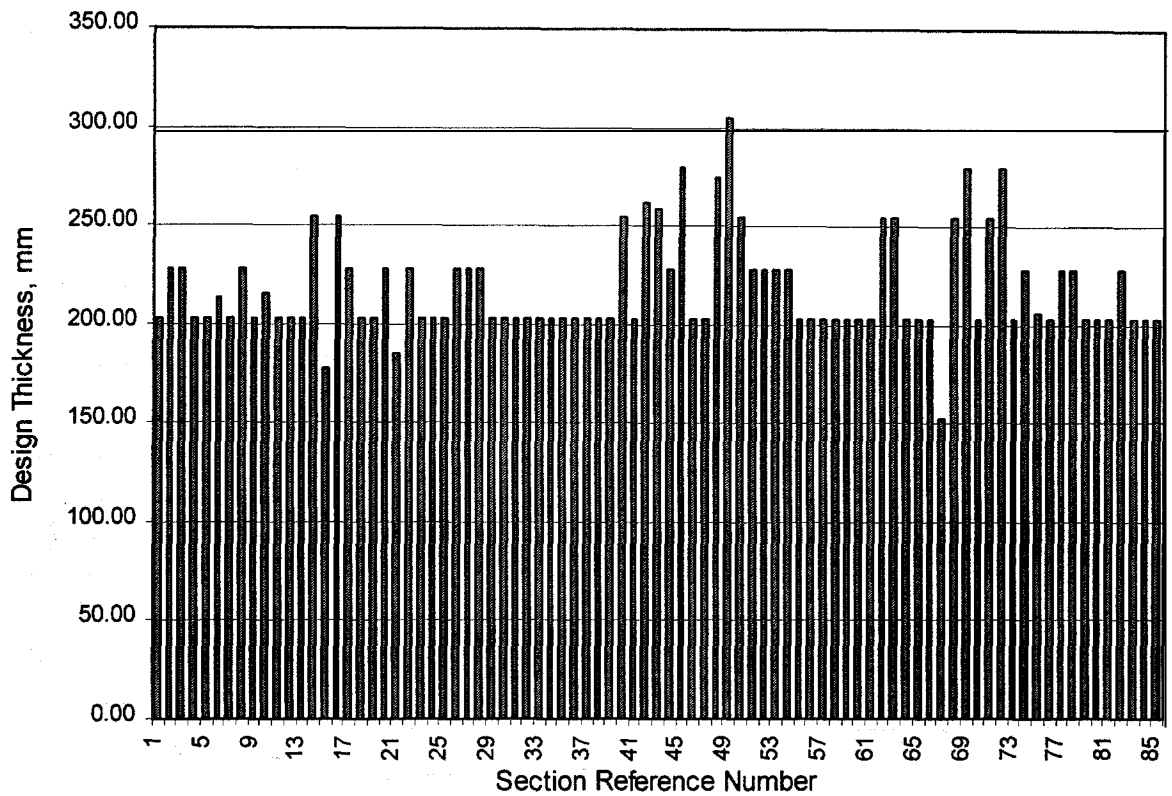

Figure 3. Design slab thickness.

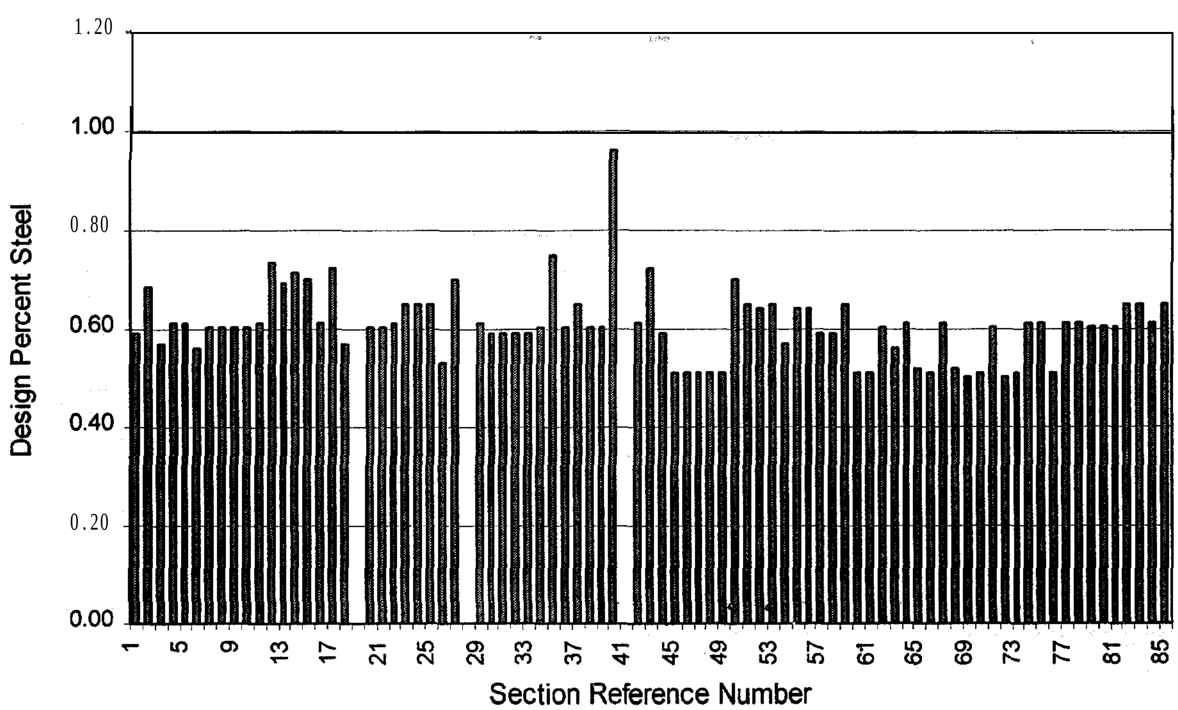

Figure 4. Design percent longitudinal steel.

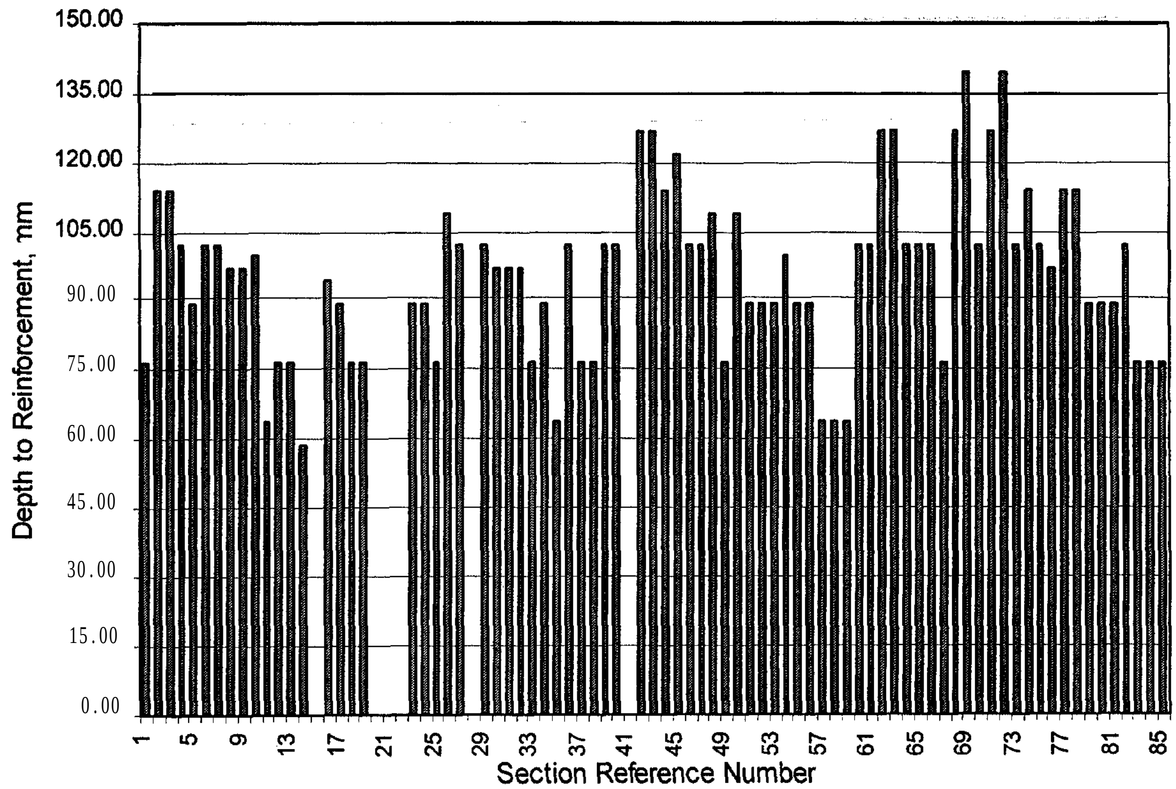

Figure 5. Depth to longitudinal reinforcement.

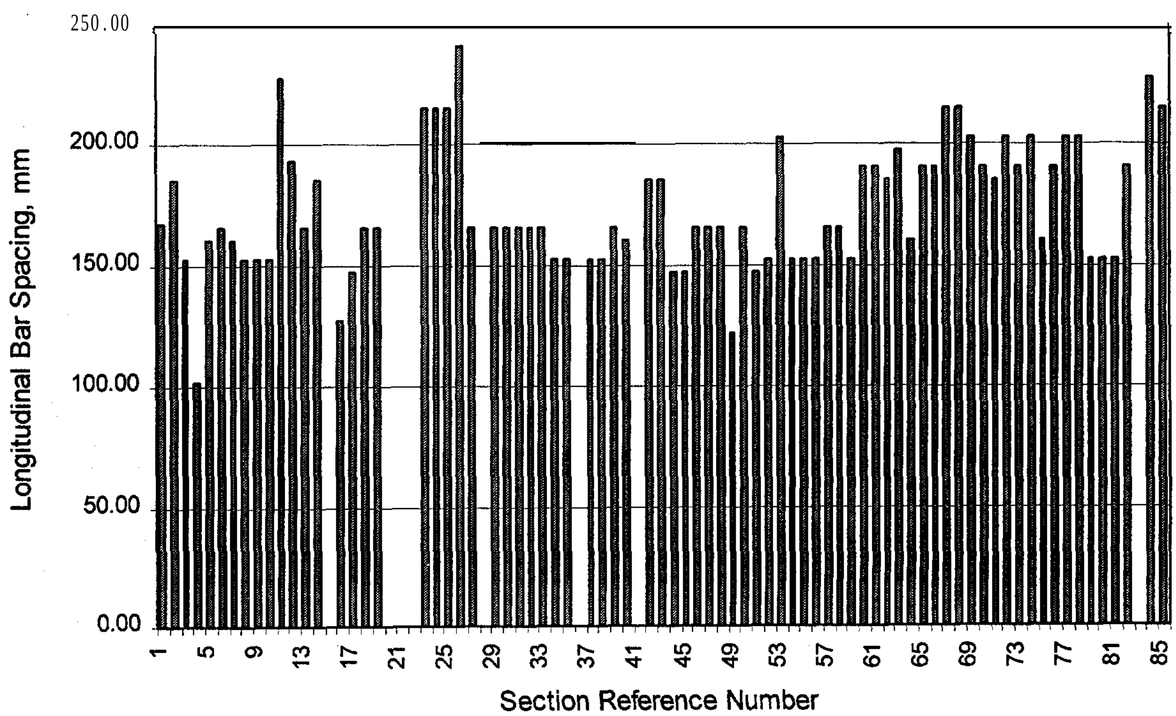

Figure 6. Longitudinal bar spacing.

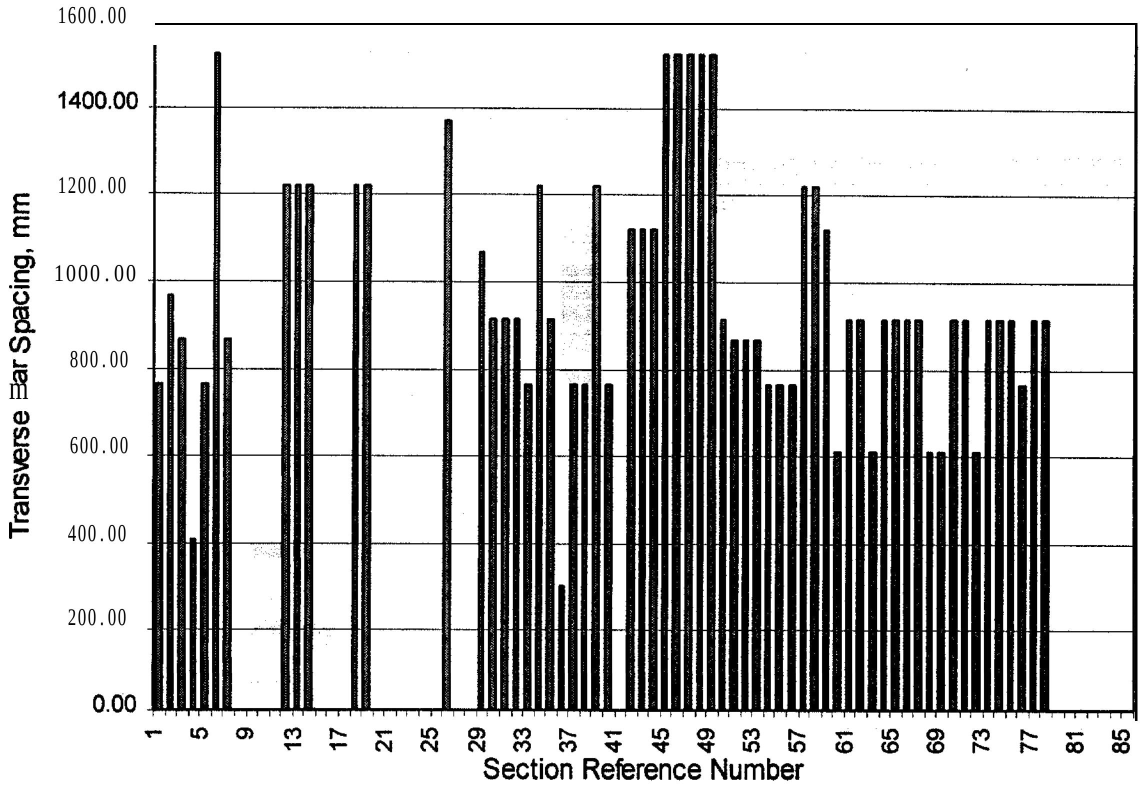

Figure 7. Transverse bar spacing.

2. Most sections have 0.62 percent or less longitudinal steel. Only 10 sections had steel equal to or greater than 0.7 percent. Fifteen sections had steel equal to or less than 0.5 percent.
3. Depth of longitudinal reinforcement was generally greater than 75 mm.
4. Spacing of longitudinal bars was generally more than 150 mm.
5. Where transverse bars were used, bar spacing was generally greater than 600 mm.

Base and Subgrade Inventory Data

Base material was characterized by material type as presented in table 5. The material type codes used in table 5 are as follows:

G Gravel
SC Soil Cement
ACM Dense-Graded, Hot-Laid, Central-Plant AC Mix
CAM Cement-Aggregate Mixture
LC Lean Concrete
LT Lime-Treated Subgrade Soil
CT Cement-Treated Subgrade Soil
PAM Pozzolanic-Aggregate Mixture

Data for the subgrade includes American Association of State Highway and Transportation Officials (AASHTO) soil classification and classification by soil particle size as coarse-grained (C) and fine-grained (F) (given in table 5). The subgrade type for 43 percent of the GPS-5 sections was identified as coarse-grained and 57 percent were identified as fine-grained based on the inventory data. The actual percentage distribution for subgrade types according to AASHTO classification (based on field sampling and laboratory testing) is given in table 6.

Table 6. Percentage distribution of AASHTO subgrade types for GPS-5 sections.

AASHTO Classification	No. of Sections	Percent Distribution
A-l-a	1	1.2
A-l-b	6	7.1
A-2-4	15	17.6
A-2-6	4	4.7
A-2-7	3	3.5
A-3	2	2.4
A-4	18	21.2
A-5	4	4.7
A-6	15	17.6
A-7-5	1	1.2
A-7-6	12	14.1
Not Known	4	4.7

Shoulder Type

Information on outside shoulder type is given in table 5. Forty percent of the GPS-5 sections have concrete shoulders and 60 percent of the sections have AC shoulders. The concrete shoulders are typically plain jointed ‘concrete. However, there are a few jointed reinforced concrete shoulders. There are no CRC shoulders.

Climatic Data

Climatic data for GPS-5 sections include climatic region type, average annual freezing index, average annual precipitation, and average daily temperature range. The key climatic data for GPS-5 sections are given in table 5 and are presented in figures 8 through 10. The climatic data are based on values averaged over the years that each section has been in service.

Traffic Data

The cumulative 80-kN equivalent single-axle load (ESAL) was used to characterize traffic loading. The cumulative 80-kN ESALs to the date of the distress survey were evaluated by summing the estimated annual 80-kN ESALs over the years the sections were in service up to the time of the latest distress survey. In the cases where some ESAL values were missing for a few years, regression analysis was used to estimate the annual total ESALs for these years.

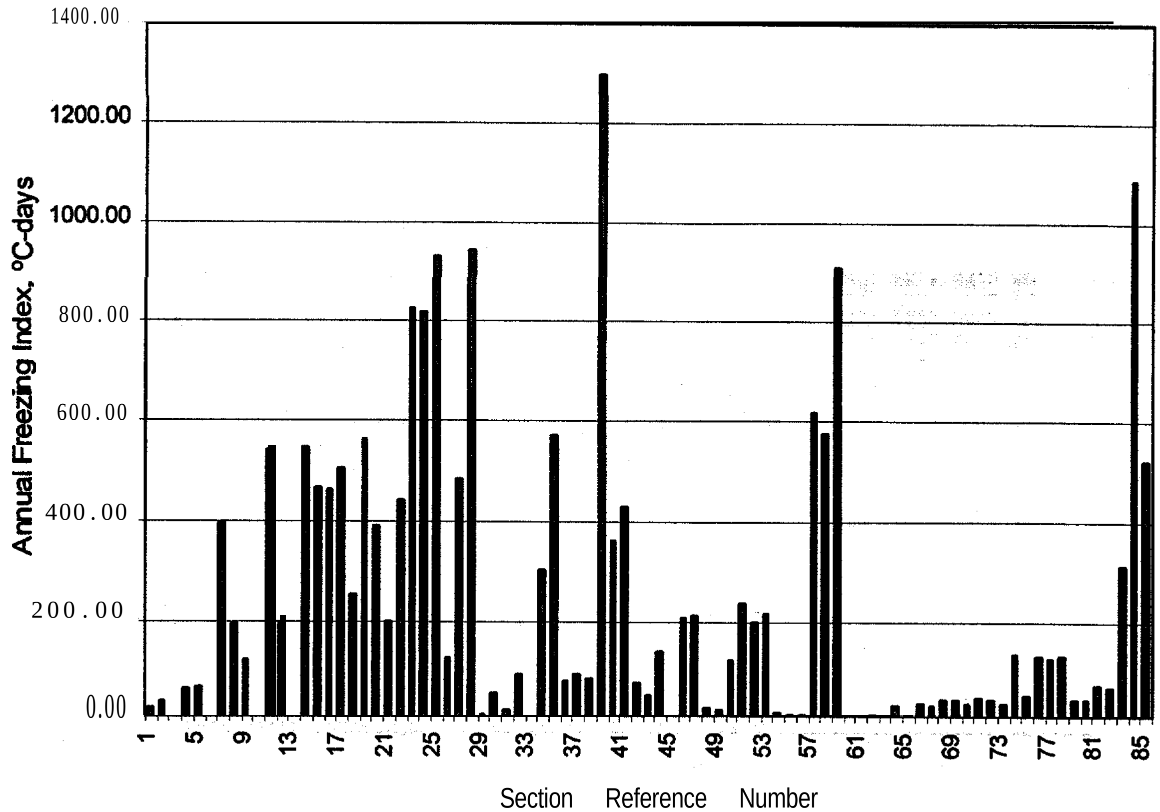

Figure 8. Annual freezing index summary.

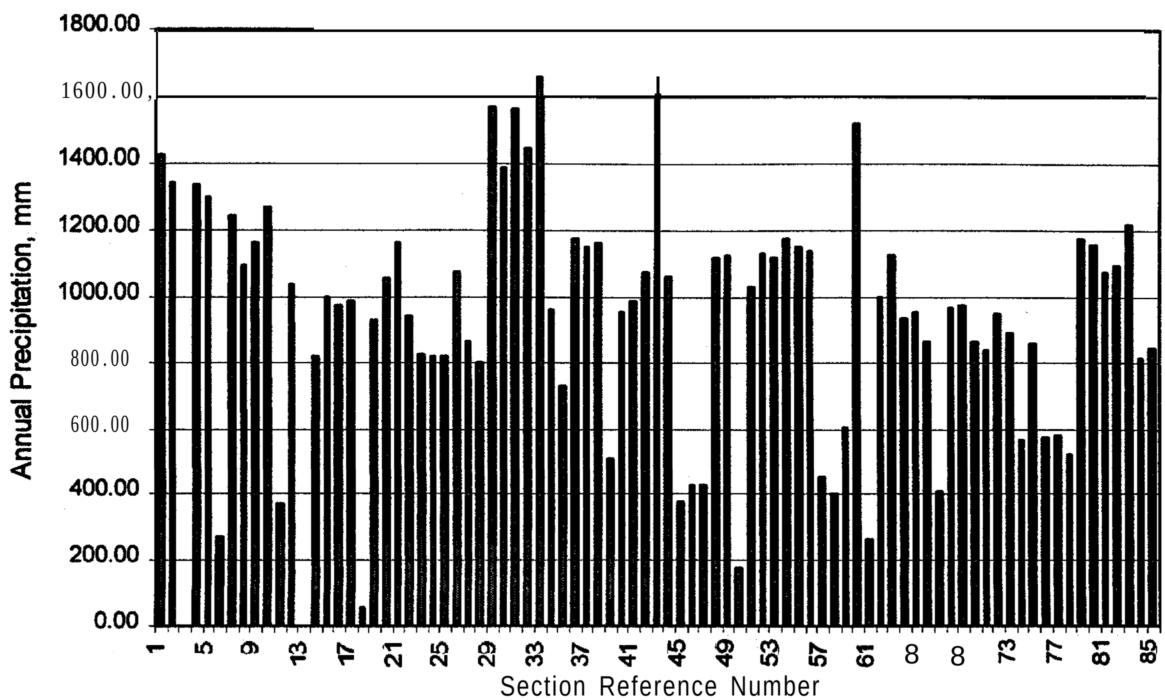

Figure 9. Annual precipitation summary.

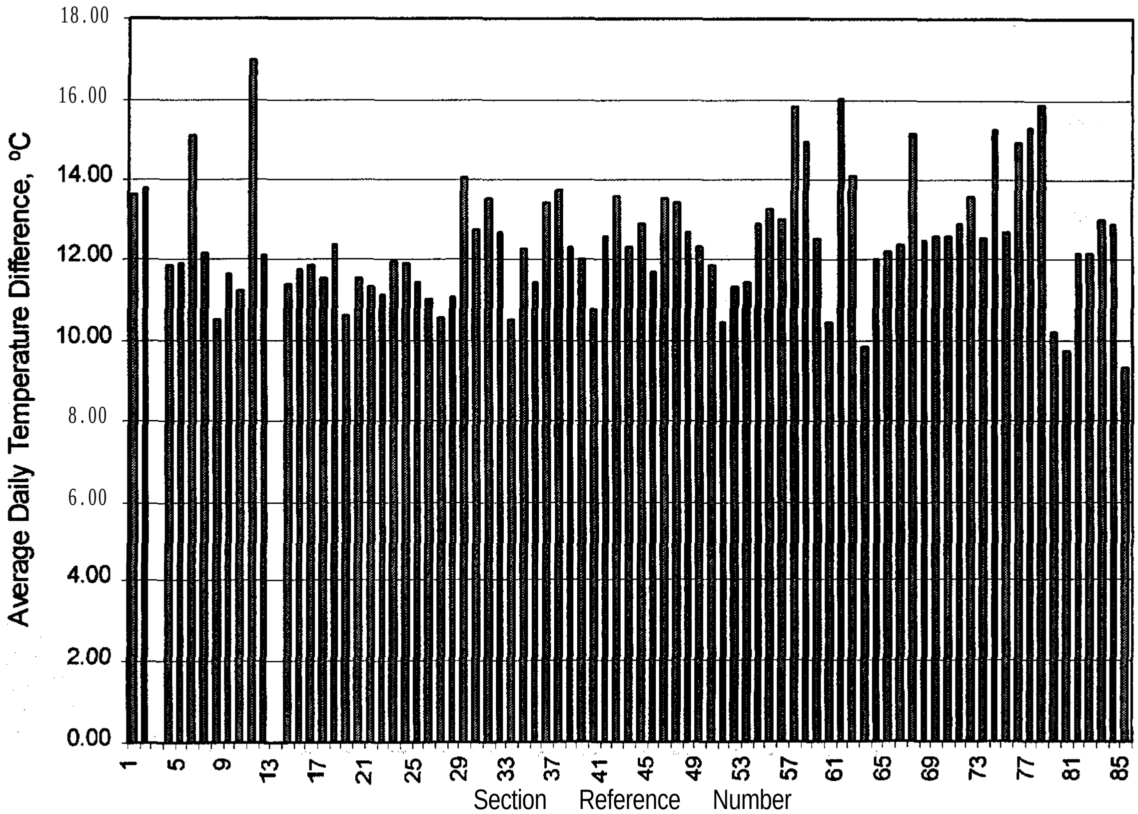

Figure 10. Average daily temperature range.

Section 24-5807 had no traffic data and was therefore not considered in subsequent analyses. A summary of the ESAL data is given in figure 11.

Profile Data

International Roughness Index (IRI) is one of the indices used in the LTPP program for characterization of pavement section roughness. IRI values determined at different test times over the years are available in the database,. Values at times that correspond to the latest distress survey dates were used for characterization of profile condition of pavement sections. A summary of IRI data is given in table 5 and figure 12. The IRI values for GPS-5 sections ranged from about 0.7 to 2.4 m/km, with a large number of sections exhibiting IRI values less than 1.8 m/km. Considering the service lives of the CRC sections in the GPS-5 experiment, the CRC pavements are exhibiting good ride characteristics.

Crack Spacing Data

The CRC pavement distress data under the LTPP program are available from two types of condition surveys: the manual distress survey and the photographic survey using the PADIAS system. For the purposes of the analysis presented in this report, the following guidelines were used:

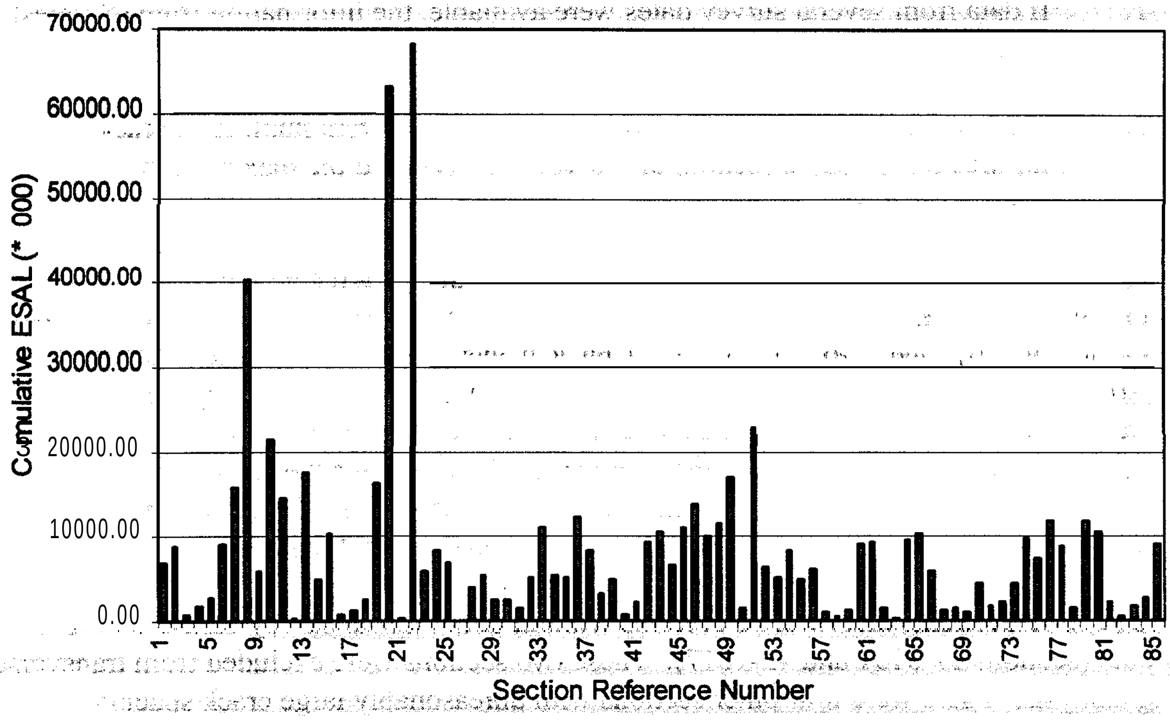

Figure 11. Cumulative ESAL summary.

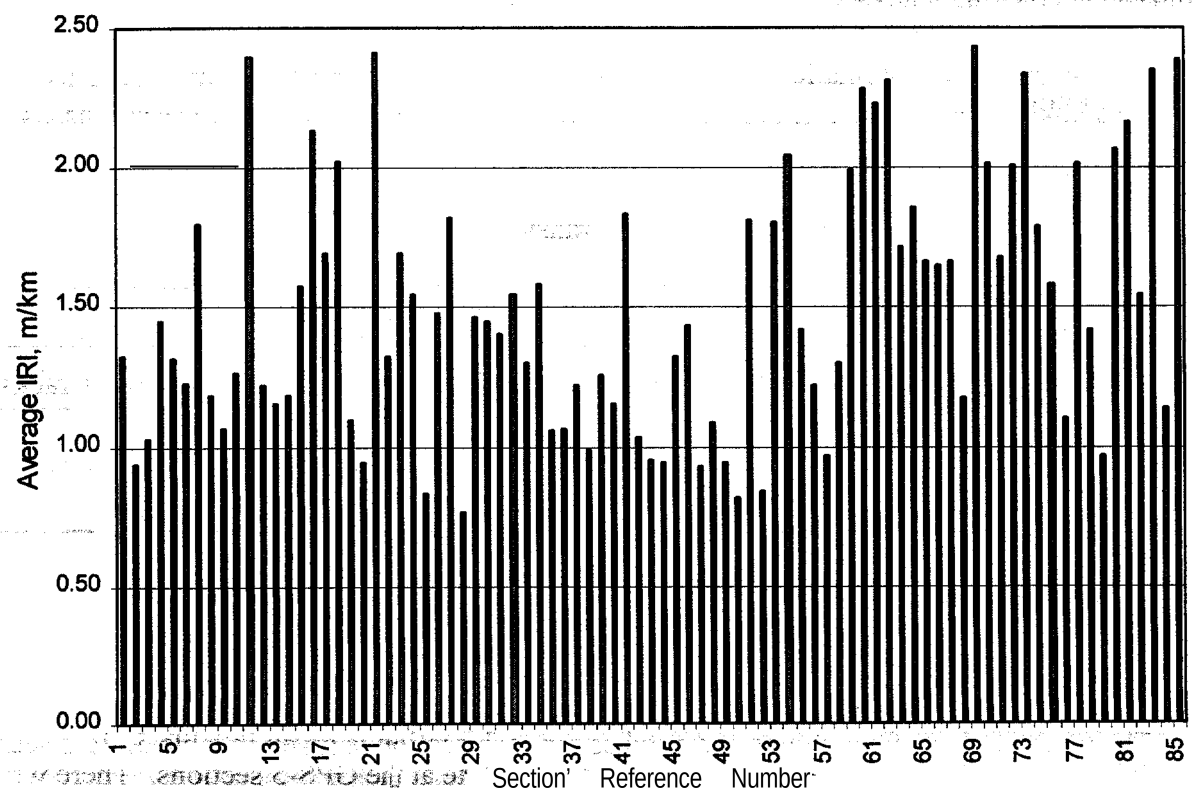

Figure 12. Average IRI summary.

1. If data from several survey dates were available, the information from the latest survey was used.

2. If the manual and PADIAS surveys indicated a different number of cracks or local failures for the same section, the survey that recorded the maximum number of cracks was used.

Average transverse crack spacing was calculated by dividing the length of the section by the total number of cracks. The total number of localized failures was found as a summation of the total number of rigid and flexible patches and punchouts. Table 5 gives a summary of GPS-5 distress survey data. Generally, PADIAS surveys predicted larger crack spacings compared to the manual survey, as shown in figure 13. The crack spacing shown in figure 13 is based on the most recent surveys listed in table 5. Overall, the average crack spacing for the GPS-5 test sections was found to be about 1.2 m (4 ft) based on manual surveys. It appears that the photographic procedure fails to adequately identify all low-severity transverse cracking.

Out of 85 sections, there were 2 sections without both manual survey data and PADIAS survey data (sections 17-5 15 1 and 42- 16 17). These two sections were excluded from transverse cracking analysis. There were four other sections with unreasonably large crack spacing calculated from the PADIAS distress survey (sections 24-5807, 41-5005, 41-7081, and 51-5010). These four sections did not have manual surveys. These four sections were also excluded from the transverse cracking analysis.

Both manual and automatic surveys indicate a very small percentage of high-severity transverse cracking and a moderate amount of medium-severity cracking in all the sections, as summarized in table 7.

Table 7. Severity of transverse cracking.

Survey Type	Percentage of Cracking		
	Low-Severity Cracks	Medium-Severity Cracks	High-Severity Cracks
Manual	78.91	21.74	0.26
PADIAS	63.14	36.27	0.59

Note: Based on total amount of cracking.

Punchout and Patching Data

The total number of punchouts and patches for each section is given in table 5. It is seen that localized failures have not been a serious problem to date at the GPS-5 sections. There were 16 sections exhibiting localized failure, as summarized below:

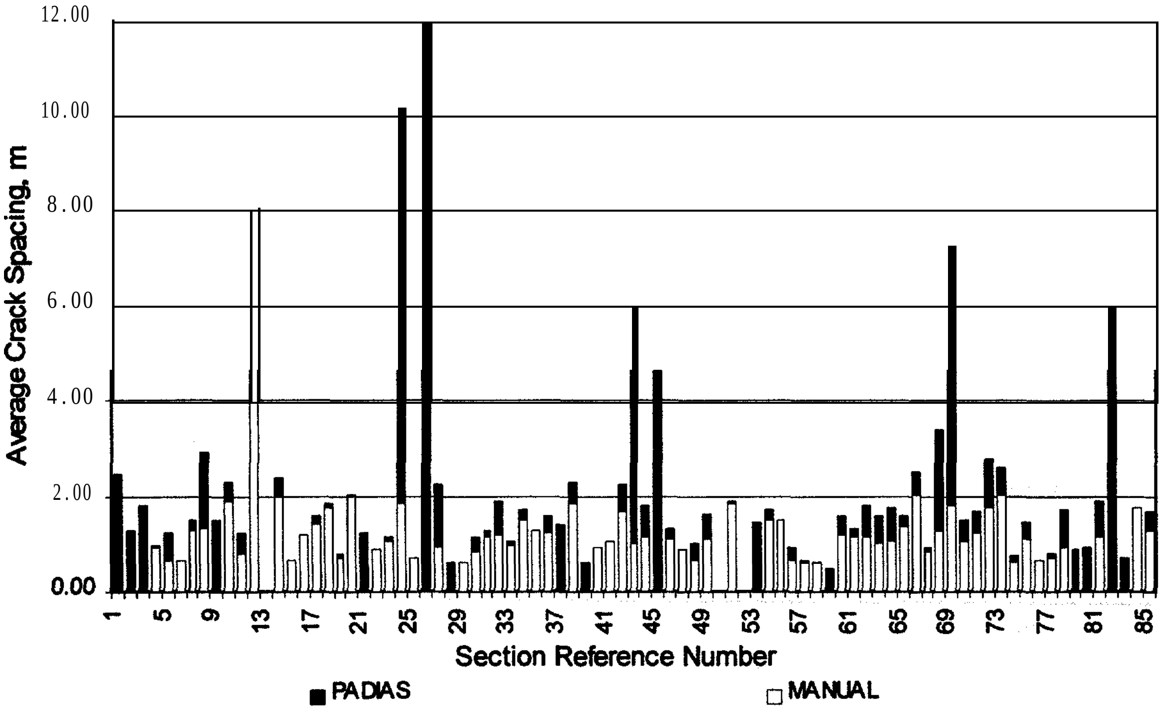

Figure 13. Average crack spacing.

Total Number of Failures	Number of Sections
1	5
2	5
3	3
4	1
5	0
6	2

One section reportedly exhibited 23 **punchouts/patches.** This is considered an error in interpretation of the distress data. Twenty-three localized failures over a length of 152.4 m would equate to a rate of about 150 localized failures per kilometer. It is unlikely that any highway agency would permit such a high amount of localized failures to remain on a public highway.

It should be noted that, as shown in table 5, none of the nine sections that have been overlaid and the one section that was taken out of the study exhibited no localized failures. Also, eight of the nine overlaid sections had IRI values less than 1.5 m/km. The section that was taken out of the study had an IRI value of 2.35 m/km at the time of the last profile survey. It thus appears that the appropriate overall pavement projects are performing far worse than the overlaid test sections. It further appears that performance evaluation of CRC pavements should incorporate longer lengths of pavement to ensure that representative failure conditions in the pavement are reliably obtained, Thus, the visual condition survey should include a survey of **5-** to

8-km lengths of the CRC pavement in addition to a detailed survey of the 152.4-m (500-R) monitoring length of the test section. The longer visual condition survey should record at least the number and severity of punchouts, patches, and other localized failures.

Summary

The small amount of localized failures observed at the GPS-5 test sections limits the type of analysis that can be carried out to evaluate the performance of CRC pavements. It appears that most of the CRC pavements are performing well, or rather, exceptionally well. This observation is also supported by the low IRI values determined for the GPS-5 test sections.

CHAPTER 3. EVALUATION OF CRACK SPACING DATA

Introduction

It is well established that transverse crack spacing in CRC pavements is influenced by the percent of longitudinal reinforcement, concrete strength, and slab/base interface friction. Recent efforts have also shown that the transverse crack spacing pattern is influenced significantly by the ambient weather conditions at the time of concrete placement and a few days thereafter. As such, the long-term crack spacing pattern is influenced by the conditions during the first few days after concrete placement. The LTPP database contains no data on ambient weather conditions during time of concrete placement. In addition, data on specific dates of construction of the test section portion of the roadways are not available. Thus, analysis of the crack spacing patterns for the GPS-5 sections have to rely on other attributes that relate to the properties of the CRC pavement and general climatic data.

Another data type that is currently not available is the data on individual crack spacing. Without this data, analysis of the characteristics of the crack spacing pattern is not possible. Previous studies have shown that frequency distribution curves for crack spacing and plots of "average spacing of the closest five cracks" (ASCFC) can be useful in understanding the behavior of CRC pavements and in determining potential areas of future localized failures. The ASCFC plots can identify poor crack spacing patterns within a section of CRC pavements. Cluster cracking areas and areas with large' crack spacings can be easily identified. Wide crack spacing can result in premature crack spalling and "companion" punchouts at the location of wide cracks. Typical frequency distribution curves and the plots of ASCFC are shown in figures 14 and 15. It is believed that in the future, the interpretation of distress data will also include data on individual crack spacing along the 152.4-m length of each GPS-5 test section. Future analysis of the CRC pavements will also benefit if actual distress survey maps are made available to the analysts. Then it would be possible to relate the locations of the failures to crack spacing characteristics at these locations.

Another data type that is missing from the LTPP database is the crack width data. No attempt has been made to date to measure crack width at the GPS-5 test sections, Crack width data are needed to study the correctness of applying various crack width criteria as part of the design of CRC pavements.

Bi-Variate Plots

The following independent variables were selected to analyze their effect on-crack spacing:

- Age at the time of distress survey.
- Cumulative ESALs.
- Slab thickness.
- Elastic modulus of the concrete.
- Design percent steel.
- Depth to the reinforcement.
- Freeze index.
- Annual precipitation.
- Daily temperature range.

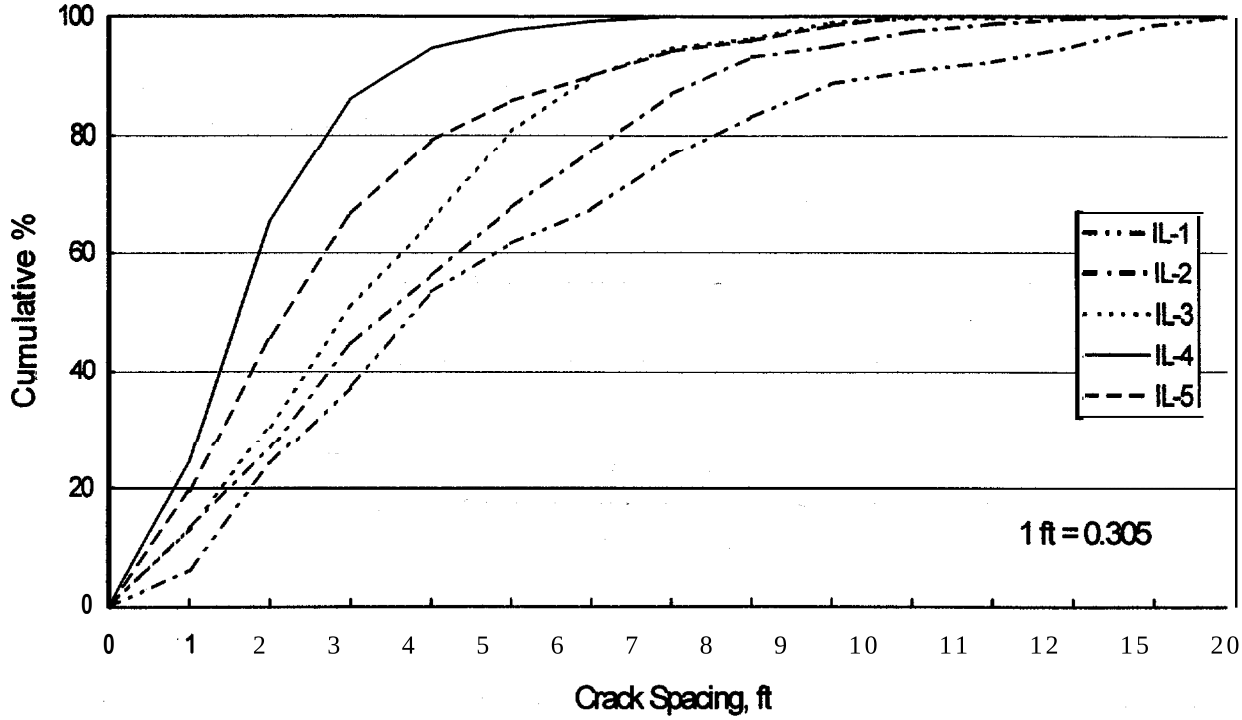

Figure 14. Typical crack spacing distribution plot for a CRC pavement[3].

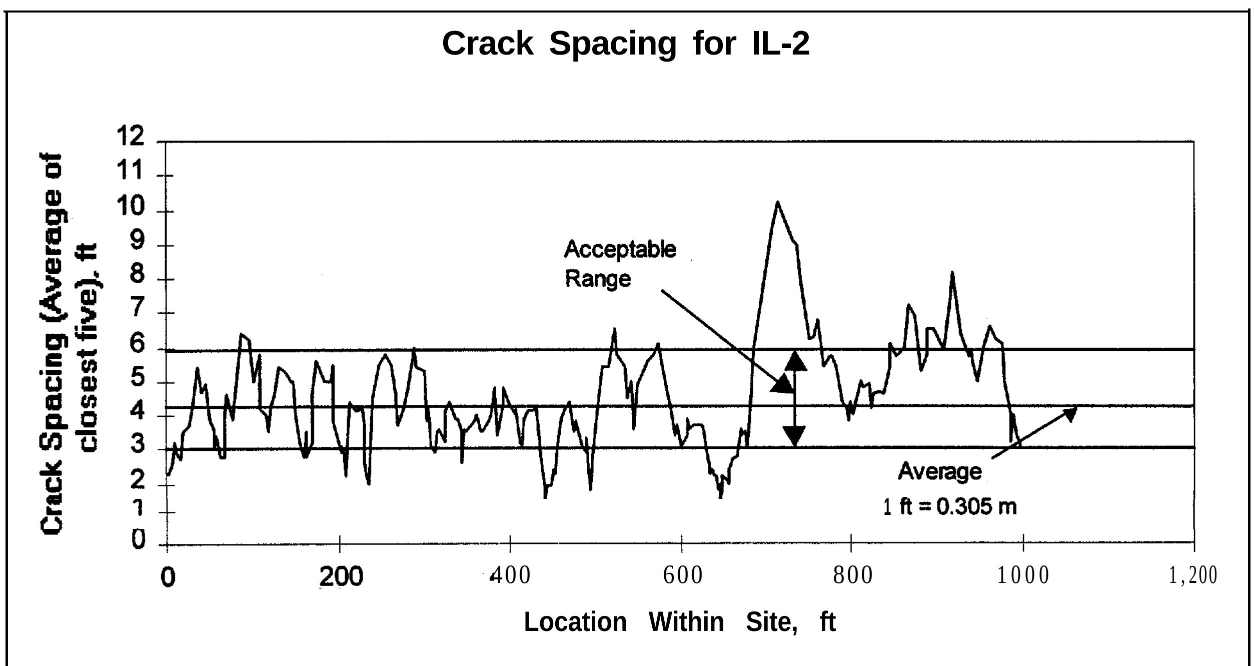

Figure 15. Typical plot of ASCFC for a CRC pavement[3].

The bi-variate plots of transverse crack spacing with respect to the above-listed independent variables are presented as follows:

Figure 16 – Crack spacing versus age.
Figure 17 – Crack spacing versus cumulative ESALs.
Figure 18 – Crack spacing versus slab thickness.
Figure 19 – Crack spacing versus concrete modulus of elasticity.
Figure 20 – Crack spacing versus percent longitudinal steel.
Figure 21 – Crack spacing versus percent longitudinal steel (age < 10 years).
Figure 22 – Crack spacing versus percent longitudinal steel (age > 10 years).
Figure 23 – Crack spacing versus depth to longitudinal reinforcement.
Figure 24 – Crack spacing versus annual air freezing index.
Figure 25 – Crack spacing versus annual precipitation.
Figure 26 – Crack spacing versus average daily temperature range.
Figure 27 – Crack spacing versus longitudinal bar spacing.

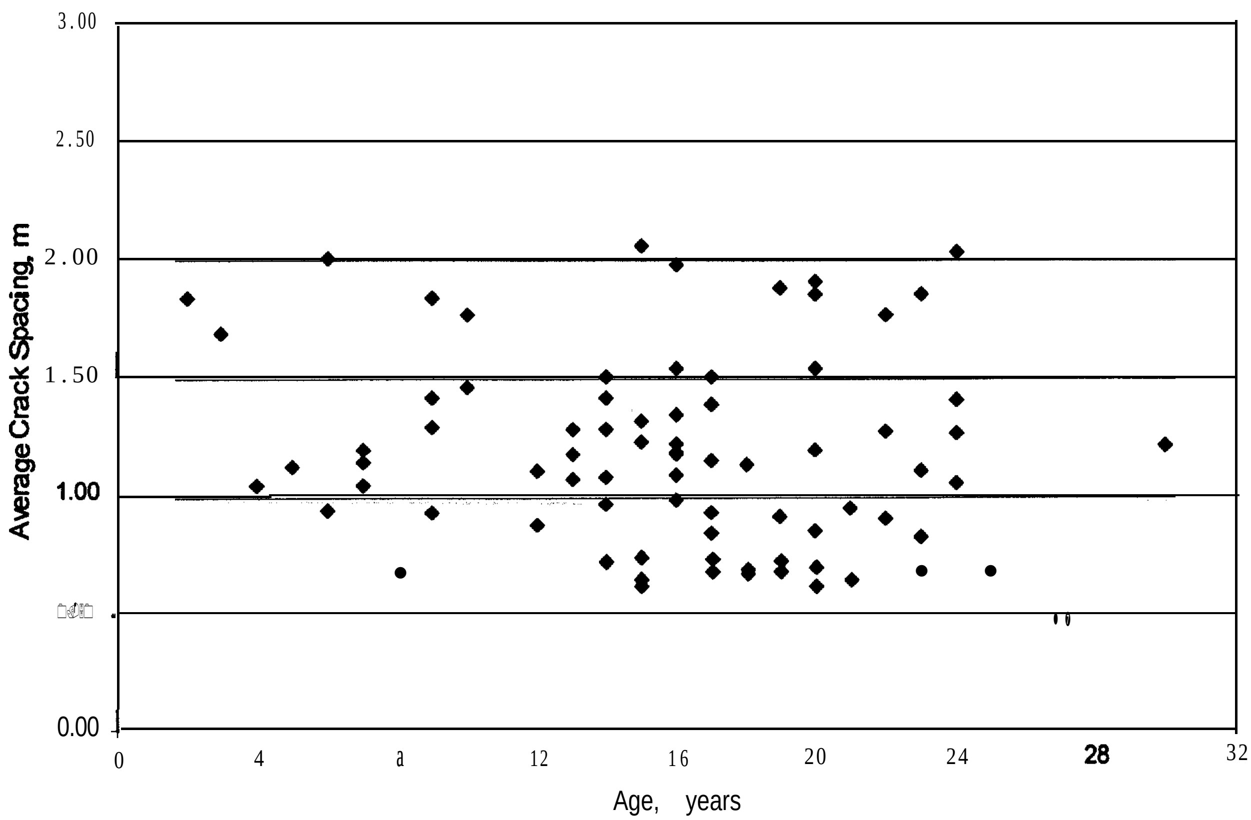

Figure 16. Crack spacing versus age.

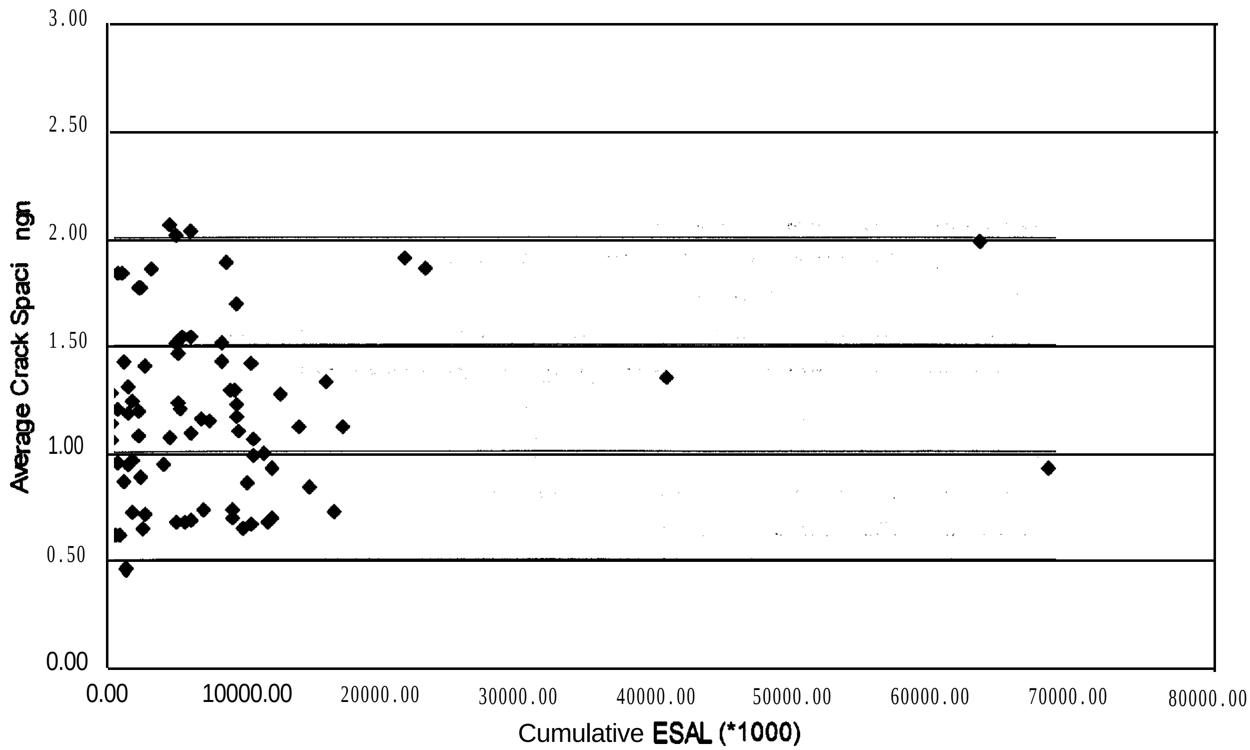

Figure 17. Crack spacing versus cumulative ESALs.

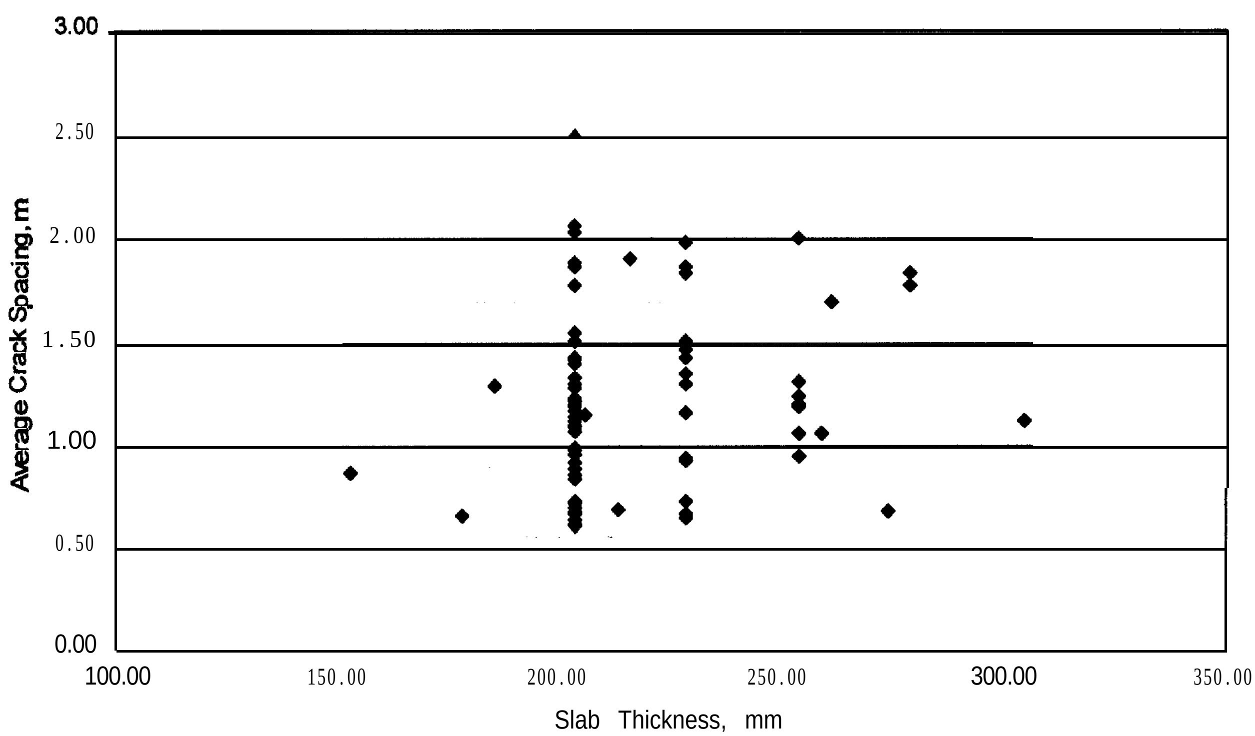

Figure 18. Crack spacing versus slab thickness.

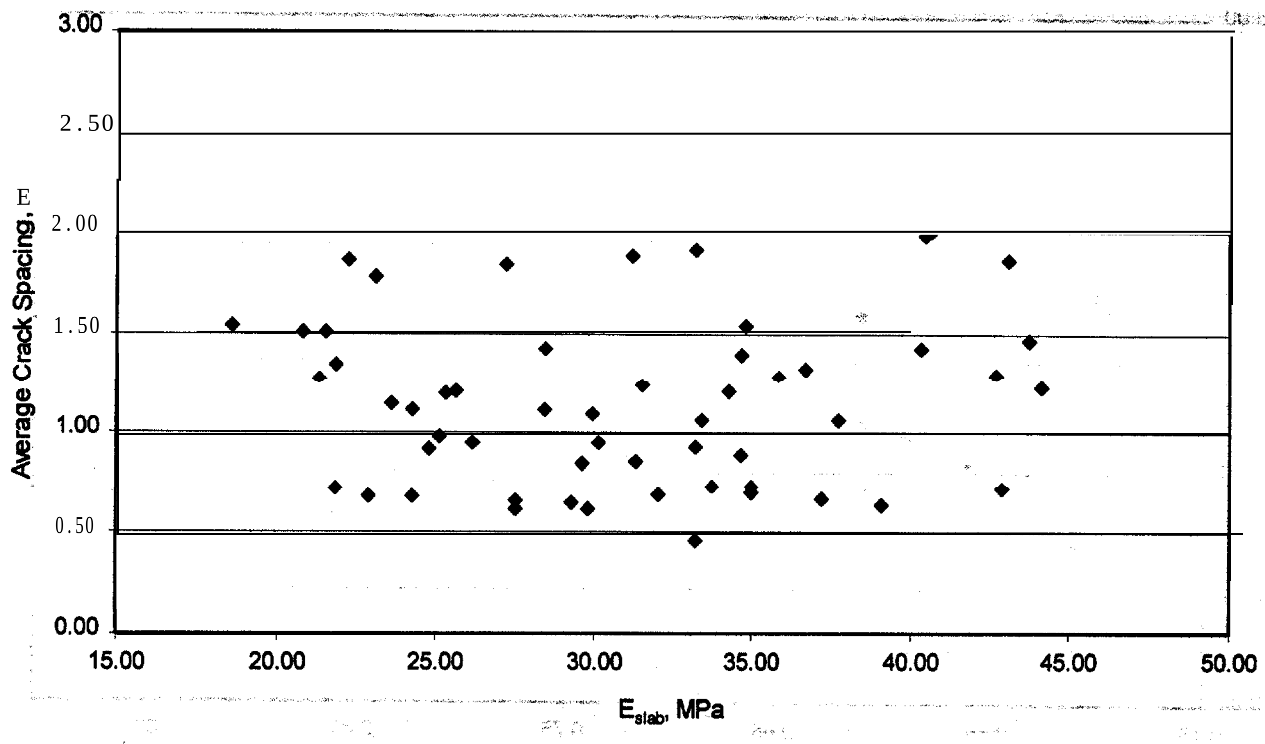

Figure 19. Crack spacing versus concrete modulus of elasticity, E_{slab}.

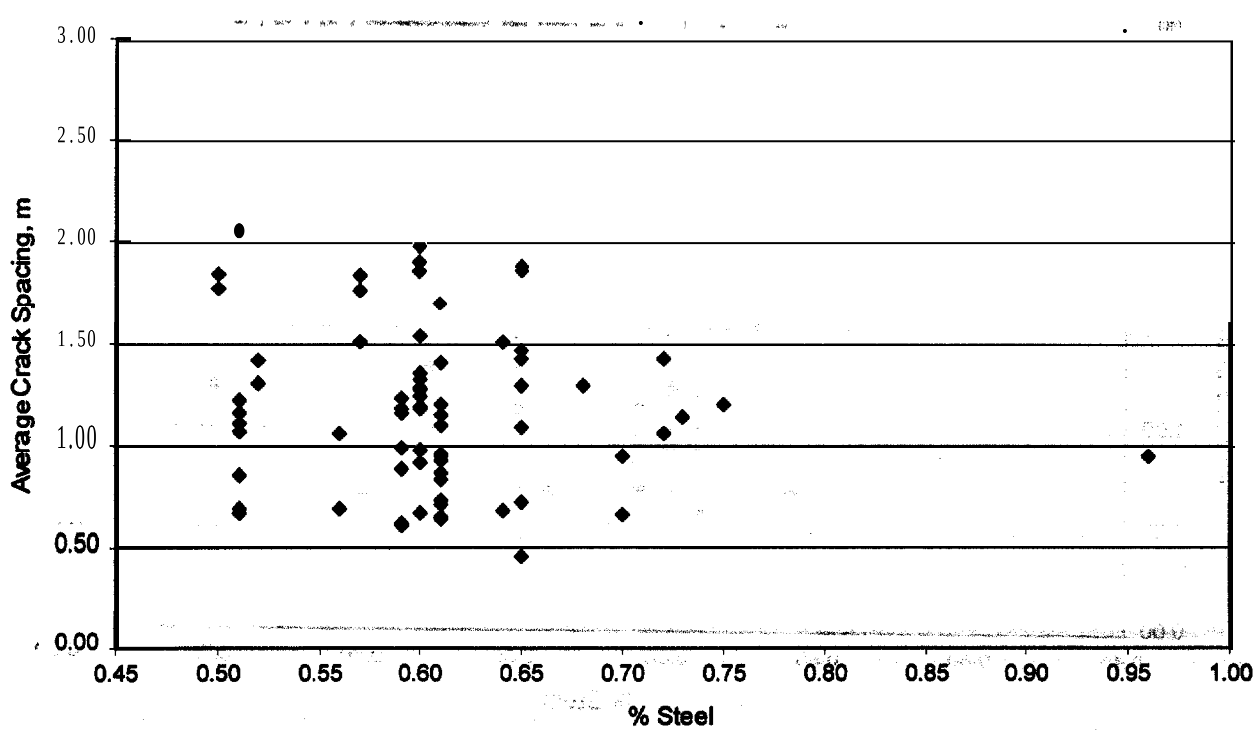

Figure 20. Crack spying. versus percent longitudinal steel.

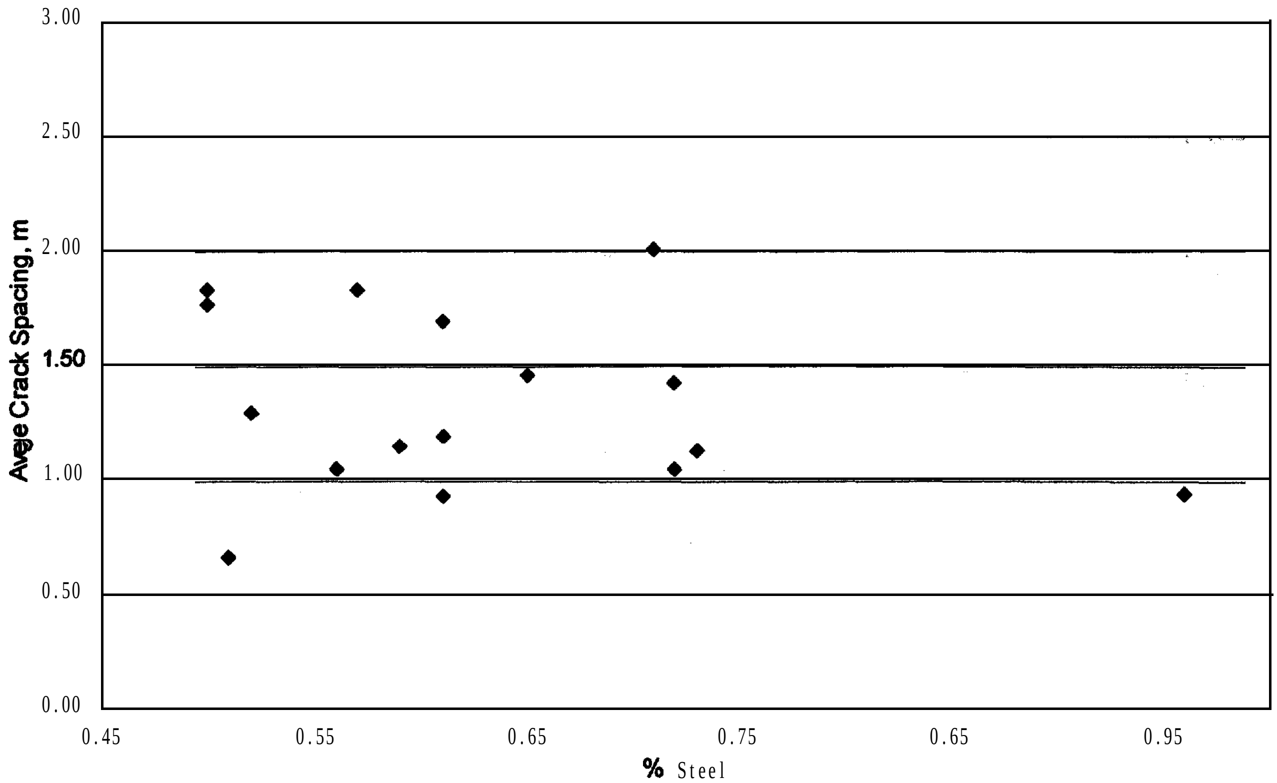

Figure 21. Crack spacing versus percent longitudinal **steel** (age < 10 years).

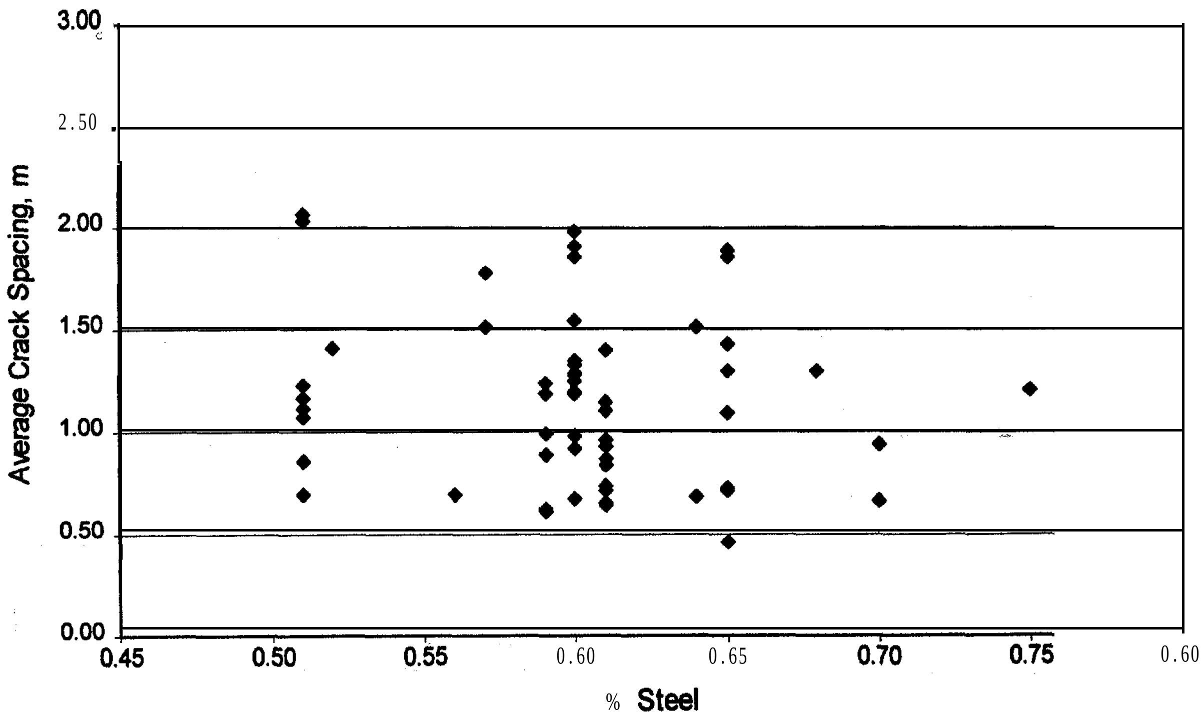

Figure 22. Crack spacing versus percent longitudinal steel (age > 10 years).

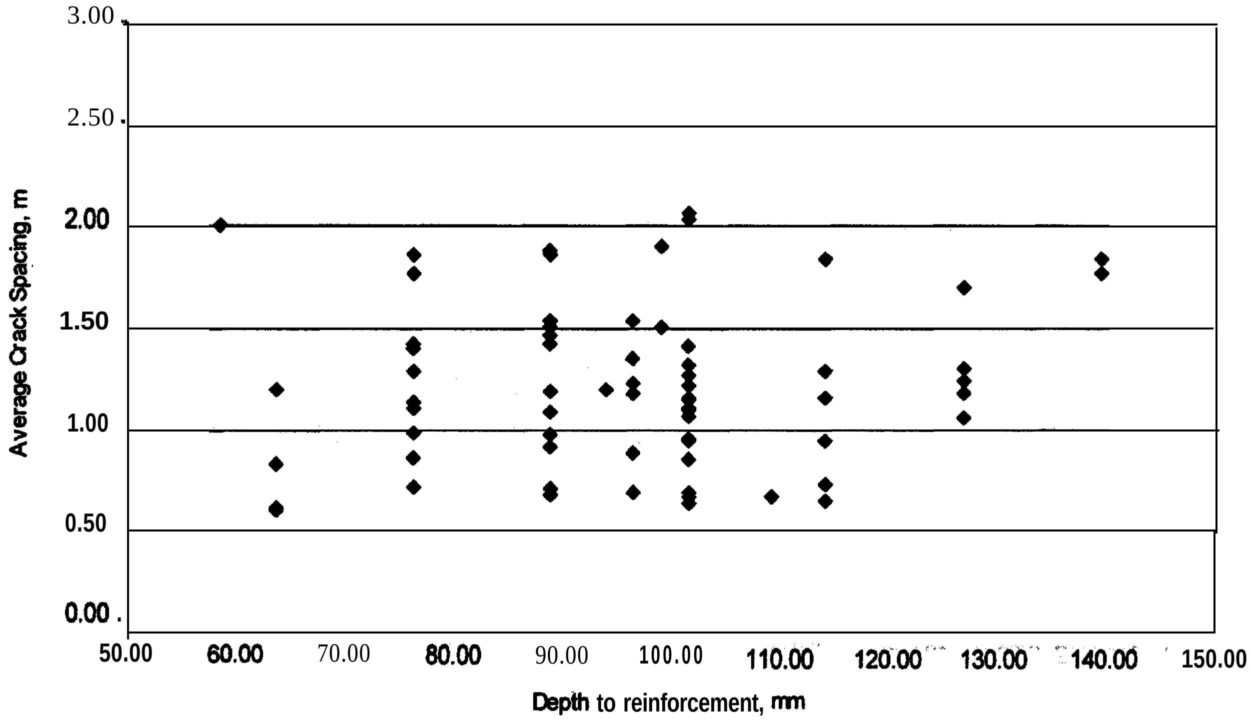

Figure 23. Crack spacing versus depth to longitudinal reinforcement.

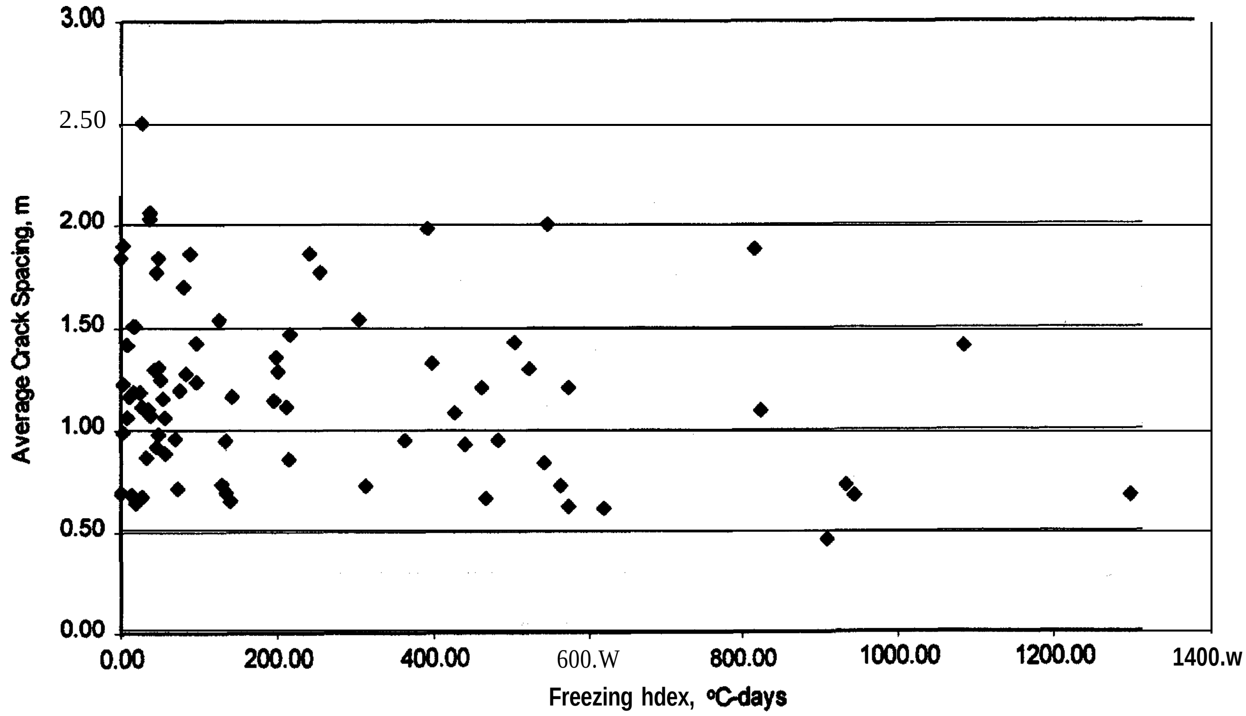

Figure 24. Crack spacing versus annual air freezing index.

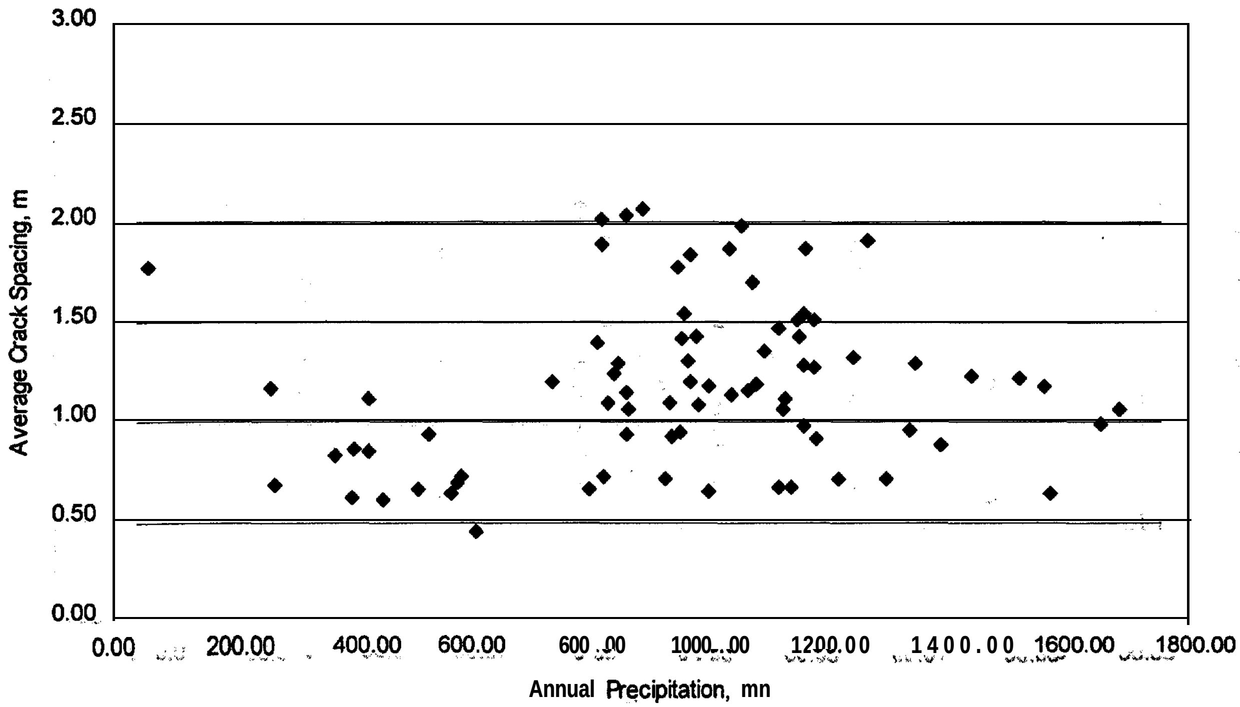

Figure 25. Crack spacing versus annual precipitation.

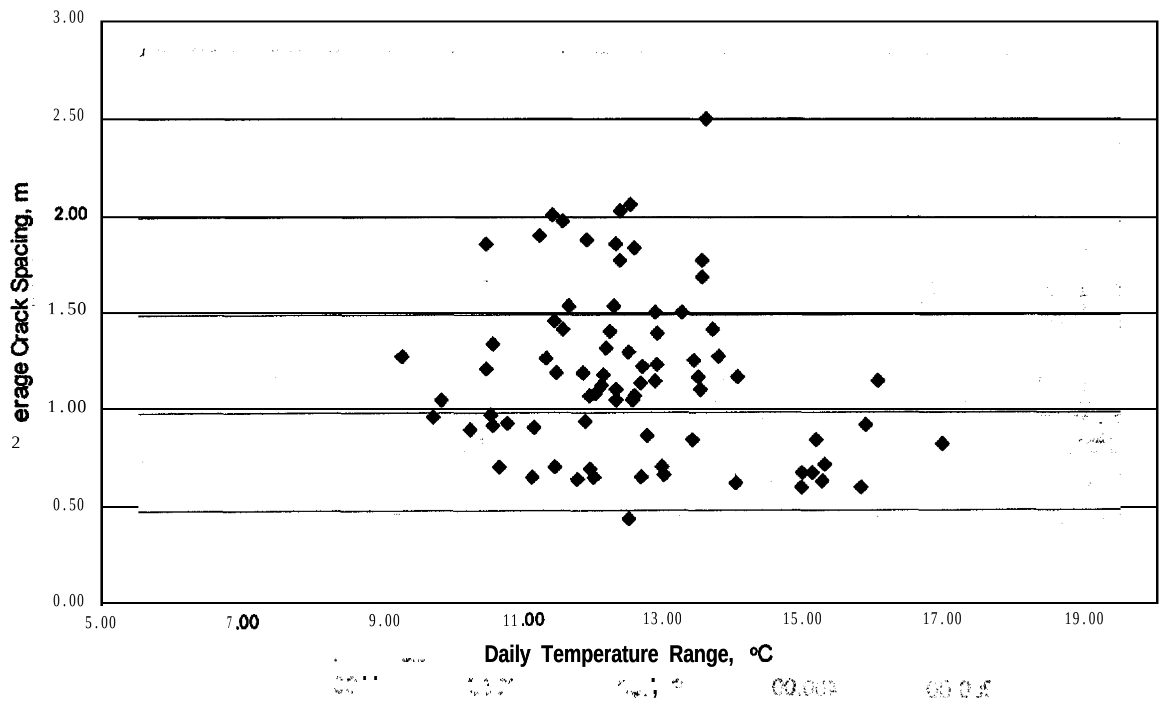

Figure 26. Crack spacing versus average daily temperature range.

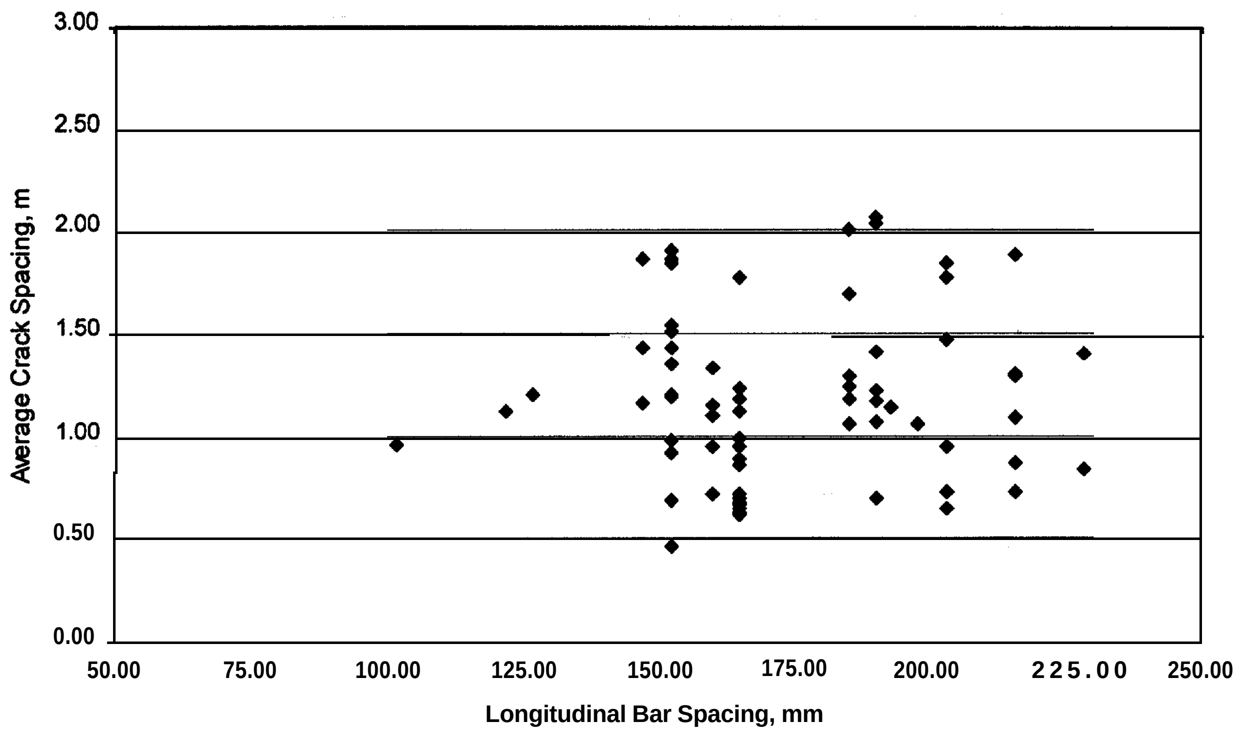

Figure 27. Crack spacing versus longitudinal bar spacing.

It is seen from a review of figures 16 through 27 that no clear trends are evident on the basis of bi-variate analysis of the data. The long-term crack spacing pattern, as represented by average crack spacing, is dependent on the interactions of possibly all of the independent variables considered together with the ambient conditions during the first few days of construction. As such, an understanding of the effect of the variables noted would have to consider the interactions and the confounding effects of each of the variables. One method to account for these effects is to use multiple regression analysis. A limited effort was made to determine if robust explanatory models could be developed for crack spacing using linear regression analysis. However, the results were not promising (low coefficient of correlations) and no further effort'was devoted to this activity. Use of empirical analysis was not part of the scope of the study and the results are therefore not reported here.

Effect of Cracking on Ride

The effect of transverse cracking on ride is shown in figure 28. No clear trends are-apparent. This is possibly due to not considering the influence of initial roughness. It should be noted that previous studies have indicated that initially smooth (as-constructed) CRC pavements generally remain smooth, and rough (as-constructed) CRC pavements tend to become rougher with time.

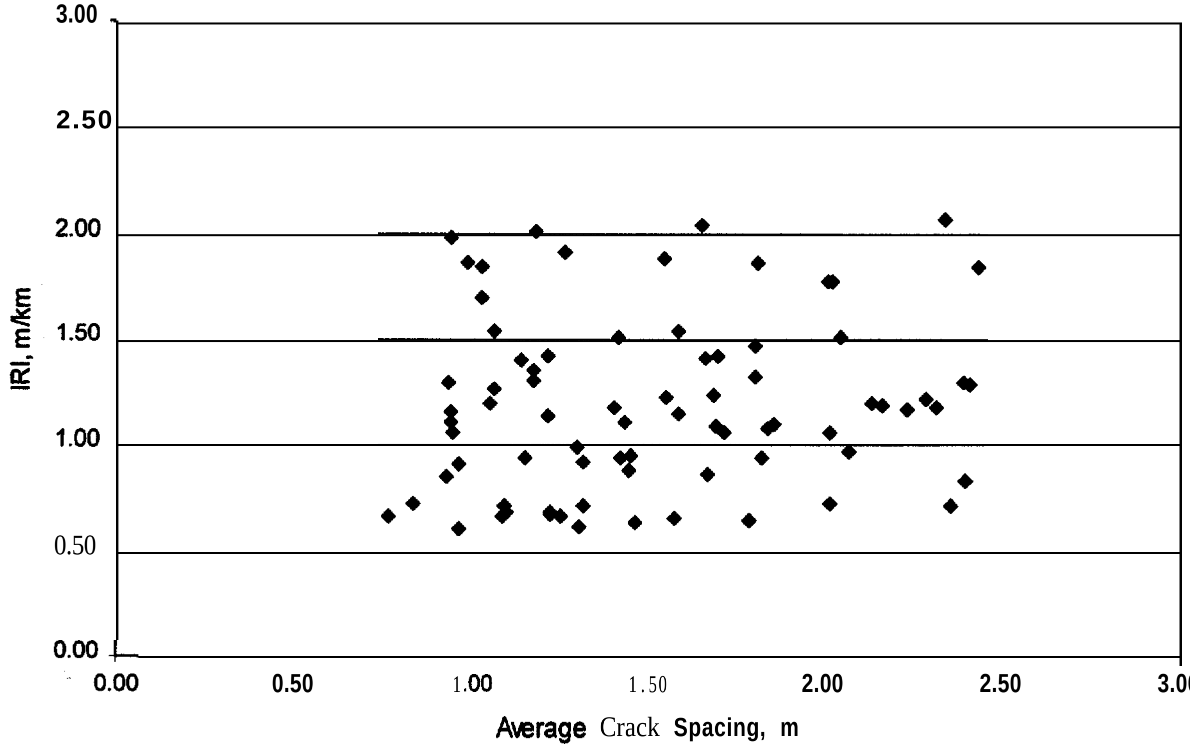

Figure 28. Effect of crack spacing on IRI.

Effect of Crack Spacing on Deflections

To determine the relationship between crack spacing and deflections as measured by the falling-weight deflectometer (FWD), average crack spacing was plotted versus load transfer efficiency and the ratio of the edge deflection and the corresponding interior deflection for sections having FWD data in the database, as shown in figures 29 and 30, respectively. No clear trends in the ‘data can be observed. It is seen that most. of the sections exhibited load transfer efficiency at cracks of 90 percent or more. The ratios of the edge deflection and the corresponding interior deflection ranged from 1 to about 2. The variability within the range is possibly due to the time of testing (curling effects), slab warping effects, and the type of shoulder.

Summary

CRC pavement behavior is characterized by crack spacing (average crack spacing and other crack spacing-related statistics) and CRC pavement performance is characterized by the number of localized failures (patches and punchouts), ride quality, and structural capacity (as determined by FWD testing). For the GPS-5 experiment, it appears that cracking data must be obtained by manual surveys and actual crack mapping must be done to allow appropriate crack spacing statistics to be determined. Also, the GPS-5 monitoring plan must include a visual survey of 5- to 8-km lengths of the project to allow reliable determination of the number of localized failures per kilometer. Crack width data are also important and should be collected over a representative subsection of the monitored length.

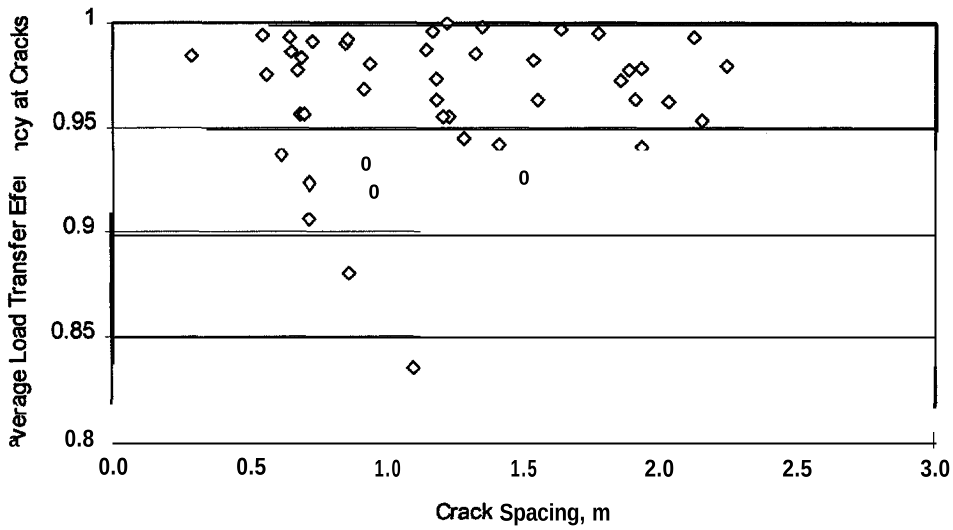

Figure 29. Average load transfer efficiency at cracks versus crack spacing.

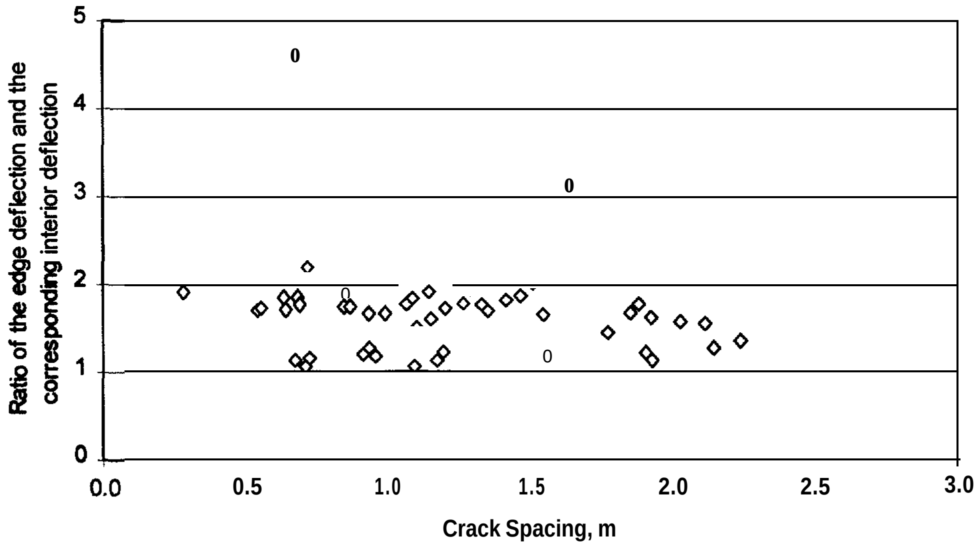

Figure 30. Ratio of maximum edge and interior deflections versus crack spacing.

CHAPTER 4. ANALYSIS OF WELL AND POORLY PERFORMING SECTIONS

In order to further understand the performance characteristics of CRC pavements, analysis was conducted of "exceptionally" well and poorly performing CRC test sections. It was expected that such an analysis would help identify some of the key design and site factors that affect the long-term performance of CRC pavements. To conduct this analysis, two groups of sections were formed using data from the GPS-5 experiment. These groups were called "Well Performing Sections" and "Poorly Performing Sections." The set of criteria used to define well and poorly performing sections is given in table 8.

Table 8. Criteria for identification of well and poorly performing sections.

Criterion	Well Performing Sections	Poorly Performing Sections
Years in Service	**20** or more	**15** or less
IRI, m/km	< 1.5	Not Considered
Severe Cracking	None	Yes
Punchouts & Patches	None	Yes

Using the above criteria, the 85 CRC pavement sections were tested. Ten sections were identified as Well Performing Sections and 13 sections were identified as Poorly Performing Sections. To find common characteristics among well or poorly performing sections, the following factors were considered as possibly affecting CRC pavement performance:

- Design parameters
  - Design percent longitudinal steel
  - Depth to reinforcement
  - Longitudinal bar spacing
  - Transverse bar spacing
  - Reinforcement placement method
  - Mean slab thickness
  - Slab elastic modulus
  - Base type
  - Base thickness
  - Base elastic modulus
  - Subgrade type (coarse/fine)
  - Soil k-value
  - Outside shoulder type

- Climatic conditions
  - Climatic region
  - Average annual freeze index

- Annual precipitation
- Average daily temperature range

- Traffic loading data

  - Traffic opening date (age as tested)
  - Cumulative 80-kN ESAL

- Distress data

  - Average crack spacing from manual and PADIAS crack surveys
  - Average IRI
  - Load transfer efficiency

Tables 9 and 10 present lists of well and poorly performing sections together with the key complementary data. The key data were compared on a case-by-case basis for the well and poorly performing sections and for all sections of the GPS-5 experiment. The results, as plotted, are given in the following figures:

Figure 29 – Comparison of design percent longitudinal steel.
Figure 30 – Comparison of depth to reinforcement.
Figure 3 1 – Comparison of longitudinal bar spacing.
Figure 32 – Comparison of transverse bar spacing.
Figure 33 – Comparison of slab thickness.
Figure 34 – Comparison of concrete modulus of elasticity as tested.
Figure 35 – Comparison of base thickness.
Figure 36 – Comparison of base modulus of elasticity as backcalculated.
Figure 37 – Comparison of subgrade k-value as backcalculated.
Figure 38 – Comparison of annual air freezing index.
Figure 39 – Comparison of annual precipitation.
Figure 40 – Comparison of daily temperature range.
Figure 41 – Comparison of crack spacing.
Figure 42 – Comparison of IRI values.
Figure 43 – Comparison of age.
Figure 44 – Effect of climatic condition.
Figure 45 – Effect of reinforcement placement.
Figure 46 – Effect of base type.
Figure 47 – Effect of subgrade type.
Figure 48 – Effect of shoulder type.

No clear trends are readily apparent for well and poorly performing pavements. For the numerical parameters discussed above, the two-sample t-test (with unequal variances assumption) was utilized to determine if the group means for the parameters in question for well and poorly performing groups were significantly different. The results indicated that the slab thickness and the concrete modulus of elasticity were significantly different at a level of significance of 0.05.

Table 9. Lists of well performing sections and complementary data for sections

Section ID	Design % Longitudinal Steel	Depth to Reinforcement, mm	Longitudinal Bar Spacing mm	Transverse Bar Spacing, mm	Reinforcement Placement Method	Mean Slab Thickness, mm	E Slab Tested, GPa	E Slab Backcalculated, GPa	Base Type Treated/ Granular	Base Thickness, mm	E Base Backcalculated, GPa
05-5803	0.61	101.60	101.60	406.40	Chairs	203.20			TB	152.40	
06-7455	0.56	101.60	165.10	1524.00	Chairs	213.36	32.04	54.00	GB	137.16	7.8
10-5005	0.60	96.52	152.40		Mech	203.20	18.60	36.60	TB	101.60	5.3
13-5023	0.60	99.06	152.40		Chairs	215.90	33.24	43.20	TB	152.40	6.3
17-9267		76.20	165.10	1219.20	Chairs	203.20	42.89	43.30	TB	101.60	6.3
31-5052	0.75	63.50	152.40	914.40	Chairs	203.20	25.67	62.20	TB	76.20	9
37-5037	0.60	101.60	762.00	304.80	Mech	203.20	21.36	34.60	TB	101.60	5
46-5020	0.59	63.50	165.10	1219.20	Chairs	203.20	27.56	34.50	TB	50.80	5
48-5334	0.51	96.52	190.50	762.00	Chairs	203.20	34.97	37.50	TB	101.60	5.4
51-2564	0.60	88.90	152.40		Other	203.20	24.80	29.60	TB	152.40	4.3

Table 9. Lists of well performing sections and complementary data for sections (continued).

Section ID	Subgrade Type Coarse/ Fine	k-value Backcalculated, MPa/mm	Outside Shoulder Type	Climatic Region	Average Annual Freeze Index, °C-days	Annual Precipitation, mm	Average Daily Temperature Range, °C	Age as Tested, year	ESAL Total (*1000)	Average Crack Spacing, m	Average IRI, m/km	LTE
05-5803	C		AC	WNF	68.61	1336.00	11.88	21	1820	0.96	1.45	0.92
06-7455	C	42.28	AC	DNF	0.53	270.00	15.13	20	8971	0.69	1.23	0.98
10-5005	C	78.31	AC	WF	125.00	1160.00	11.64	20	5976	1.54	1.07	0.98
13-5023	F	69.43	AC	WNF	1.81	1266.00	11.24	20	21332	1.91	1.26	0.96
17-9267	F	82.32	AC	WF	564.89	925.00	10.65	23	16311	0.72	1.10	1.00
31-5052	F	43.06	AC	WF	573.94	734.00	11.47	20	5263	1.20	1.05	
37-5037	F	54.74	AC	WNF	83.10	1175.00	13.43	24	12365	1.27	1.07	
46-5020	C	124.76	PCC (JRCP)	DF	619.59	451.00	15.82	20	947	0.61	0.97	0.94
48-5334	F	102.34	PCC (JRCP)	WF	133.47	574.00	14.97	25	11754	0.70	1.10	0.96
51-2564	F	90.31	PCC (JRCP)	WNF	45.13	1178.00	10.23	22	11755	0.92	0.97	0.97

LTE = load transfer efficiency

Table 10. Lists of poorly performing sections and complementary data for sections.

Section ID	Design % Longitudinal Steel	Depth to Reinforcement, mm	Longitudinal Bar Spacing, mm	Transverse Bar Spacing, mm	Reinforcement Placement Method	Mean Slab Thickness, mm	E Slab Tested, GPa	E Slab Backcalculated, GPa	Base Type Treated/ Granular	Base Thickness, mm	E Base Backcalculated, GPa
09-5001	0.60	101.60	160.02	863.60	Chairs	203.20	36.69	44.90	GB	254.00	6.5
17-5843	0.71	58.42	185.42	1219.20	Chairs	254.00	40.65	28.90	TB	101.60	4.2
37-5826	0.65	76.20	152.40	762.00	Mech	203.20	28.42	40.70	TB	38.10	5.9
39-5010					Mech	203.20	0.00		TB	101.60	
41-5021	0.51	109.22	165.10	1524.00	Other	274.32	22.91	41.50	TB	228.60	6
48-5024	0.60	127.00	185.42	914.40	Other	254.00	0.00	65.10	TB	101.60	9.4
48-5284	0.50	139.70	203.20	609.60	Chairs	279.40	0.00	39.00	TB	50.80	5.7
48-5301	0.60	127.00	185.42	914.40	Chairs	254.00	0.00	46.60	TB	50.80	6.8
48-53 10	0.50	139.70	203.20	609.60	Chairs	279.40	0.00	34.60	TB	101.60	5
48-5317	0.51	101.60	190.50	914.40	Mech	203.20	0.00	51.70	TB	50.80	7.5
48-5323	0.61	114.30	203.20	914.40	Mech	228.60	29.28	38.10	TB	152.40	5.5
48-5335	0.61	114.30	203.20	914.40	Chairs	228.601	34.97	28.901.	TB	152.401	4.2
54-5007	0.651	76.201			Chairs	203.201	21.881	24.001	TB	152.401	3.5

Table 10. Lists of poorly performing sections and complementary data for sections (continued).

Section ID	Subgrade Type Coarse/Fine	k-value Backcalculated, MPa/mm	Outside Shoulder Type	Climatic Region	Average Annual Freeze Index, "C-days	Annual Precipitation, mm	Average Daily Temperature Range, °C	Age as Tested, years	KESAL Total	Average Crack Spacing, m	Average IRI, m/km	LTE
09-5001	C	33.40	AC	WF	397.32	1243.00	12.18	15	15646	1.33	1.80	0.99
17-5843	F	56.72	AC	WF	547.61	820.00	11.42	6	4897	2.01	1.18	
37-5826	F	34.161	AC	WF	95.081	1150.00~	13.69	14	82391	1.431	2.2	0.99
39-5010	F		AC	WF	428.82	980.00	12.58	13	2272	1.08	1.84	
41-5021	F	70.51	AC	WN	27.22	1117.00	12.67	8	11588	0.67	1.0s	0.98
48-5024	F	85.31	AC	WN	14.88	999.00	14.06	13	1522	1.18	2.32	0.97
48-5284	C	83.95	PCC (JPCP)	WN	47.591	969.001	12.581	9	1019	1.841	2.43	0.98
48-5301	C	128.84	PCC (JPCP)	WN	51.541	838.001	12.911	15	1765	1.241	1.69	0.96
48-5310	F	94.68	PCC (JPCP)	WN	44.441	946.00	13.57	10	2238	1.77	2.01	0.98
48-5317	F	47.33	PCC (JPCP) I	WN	37.591	888.00	12.54	15	4426	2.06	2.34	0.99
48-5323	F	61.15	PCC (JPCP)	WF	139.09	566.00	15.26	15	9748	0.65	1.79	0.99
48-5335	C	61.01	PCC(JPCP)	WF	129.54	584.00	15.31	15	8914	0.73	2.01	0.99
54-5007	F	50.01	PCC (JPCP)	WF	312.86	1219.00	12.97	14	1751	0.72	2.35	0.91

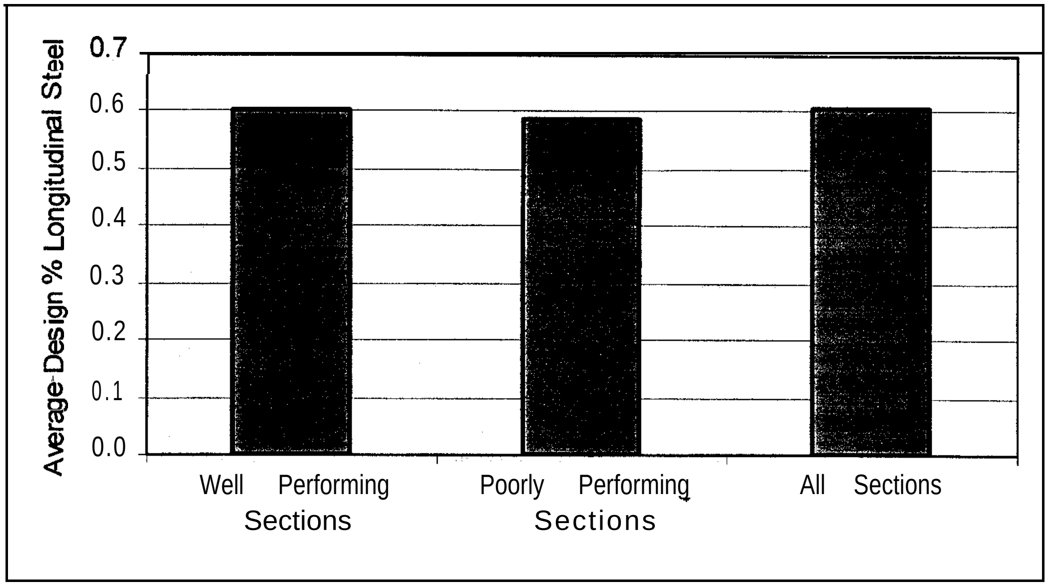

Figure 3 1. Comparison of design percent longitudinal steel.

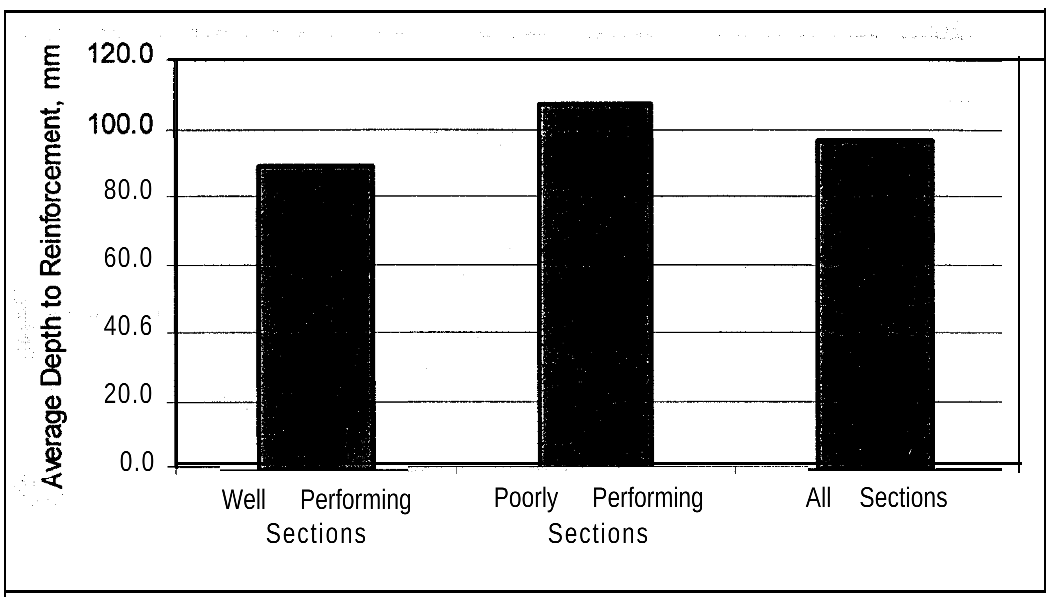

Figure 32. Comparison of depth to reinforcement.

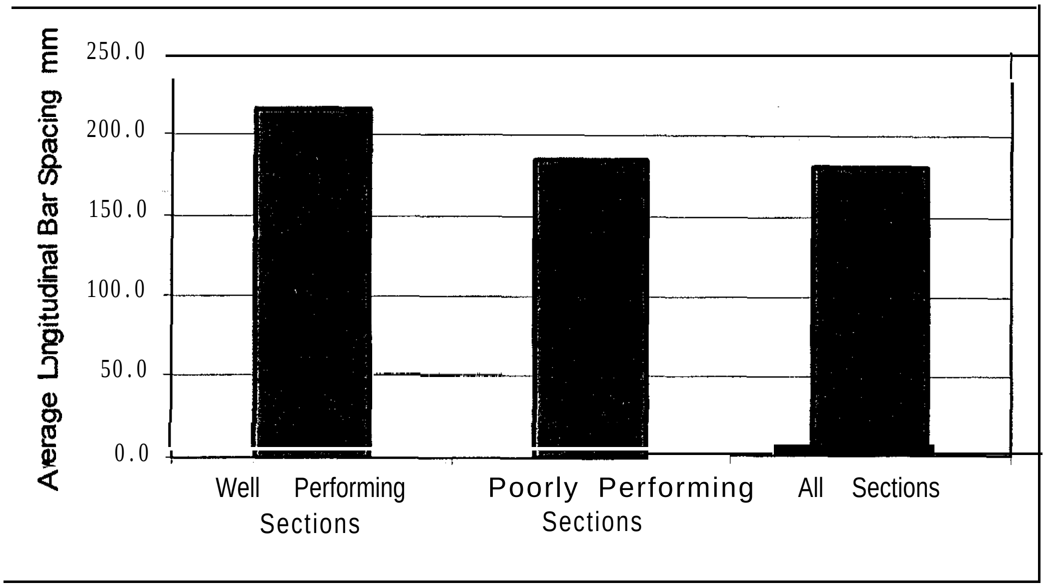

Figure 33. Comparison of longitudinal bar spacing.

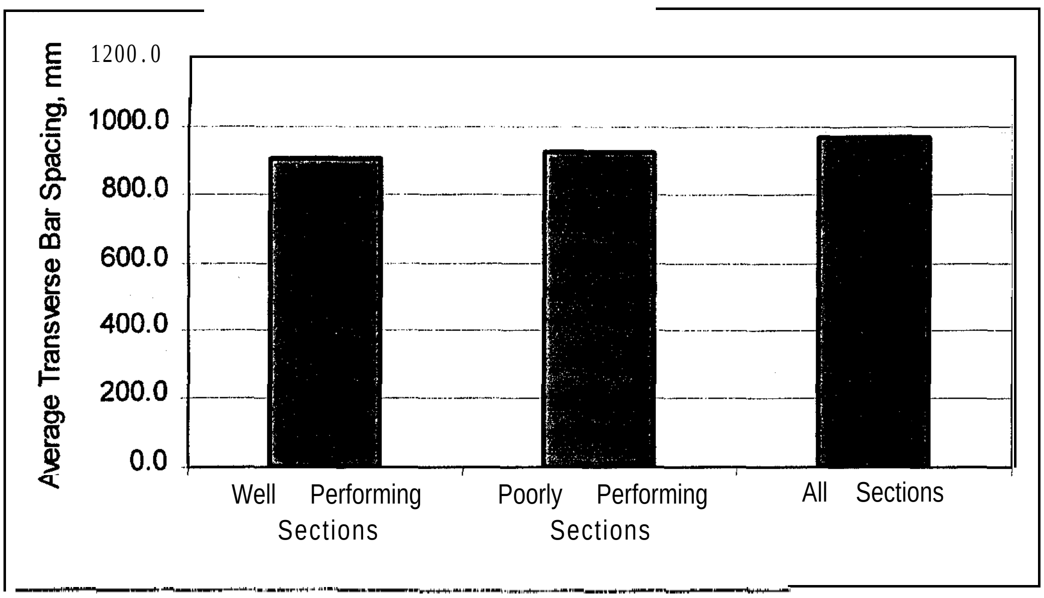

Figure 34. Comparison of transverse bar spacing.

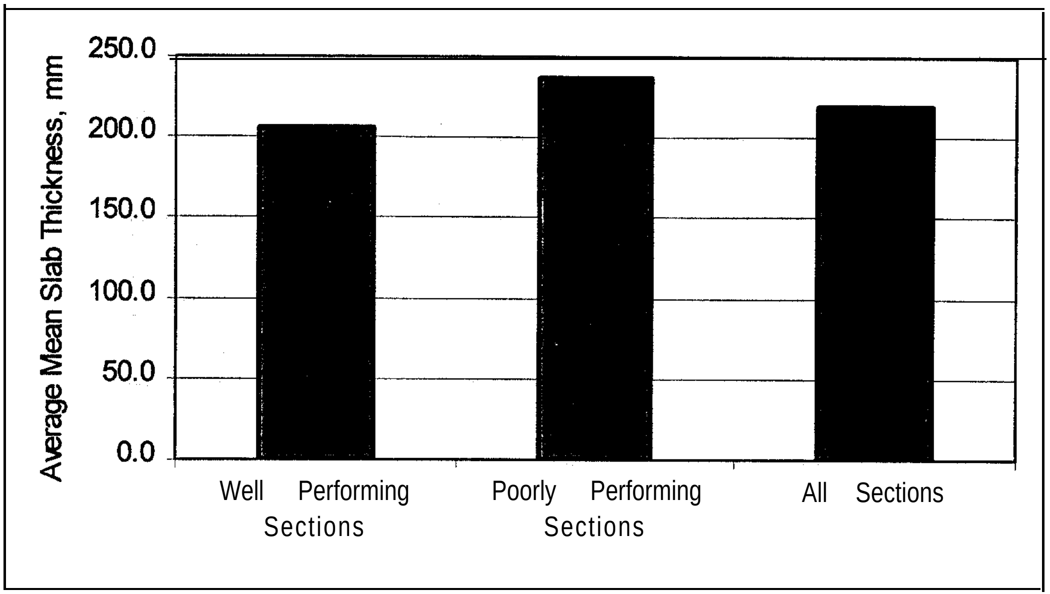

Figure 35. Comparison of slab thickness.

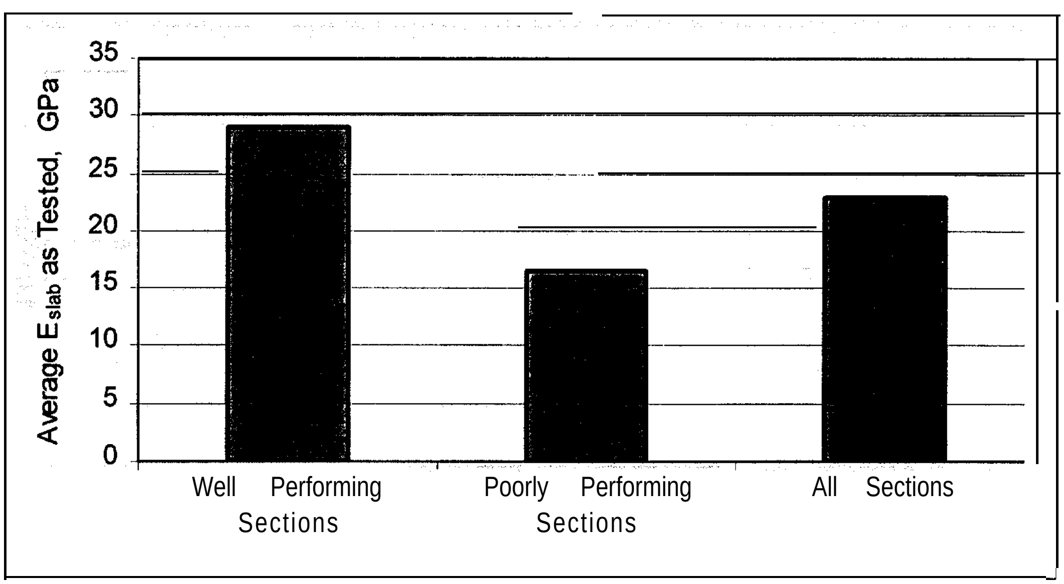

Figure 36. Comparison of concrete modulus of elasticity, E_{slab}, as tested.

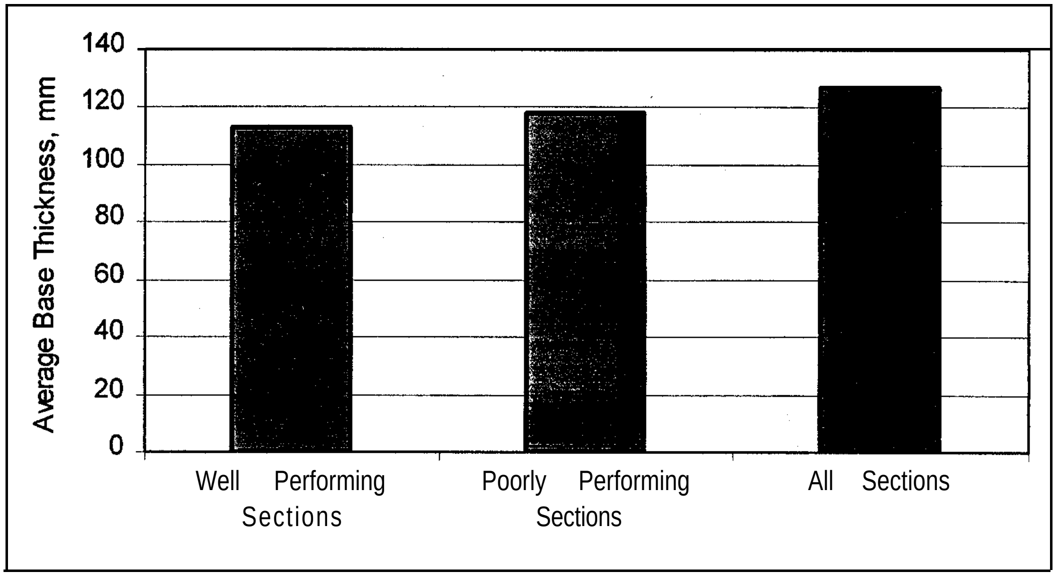

Figure 37. Comparison of base thickness.

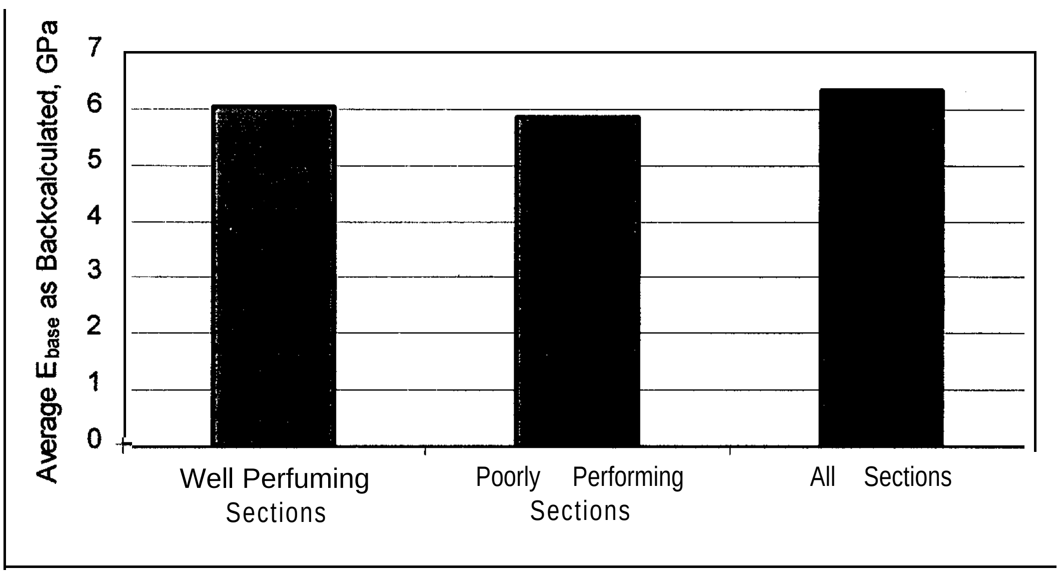

Figure 38. Comparison of base modulus of elasticity, E_{base}, as backcalculated.

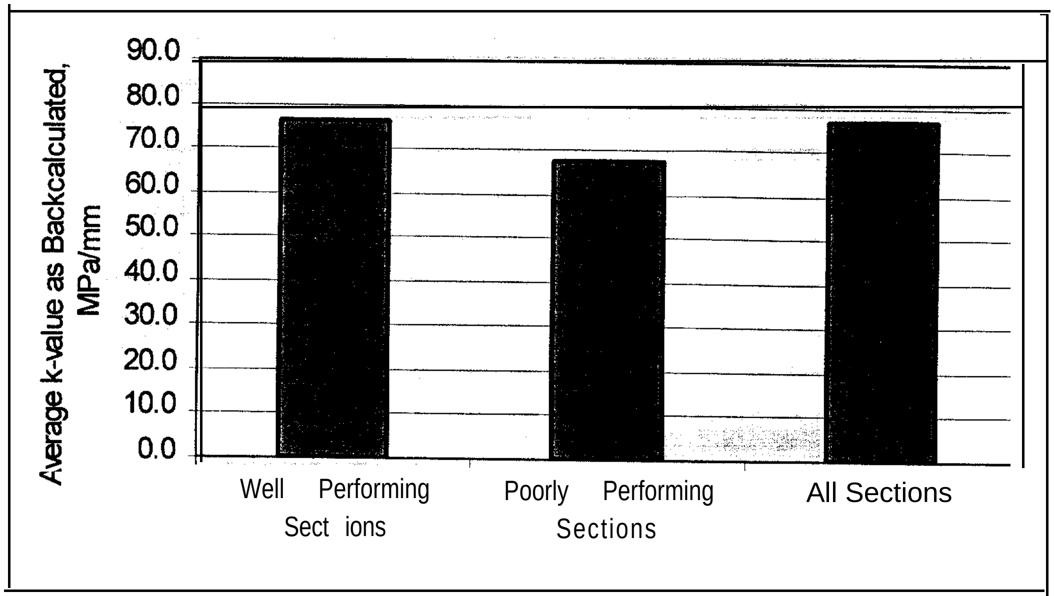

Figure 39. Comparison of subgrade k-value as backcalculated.

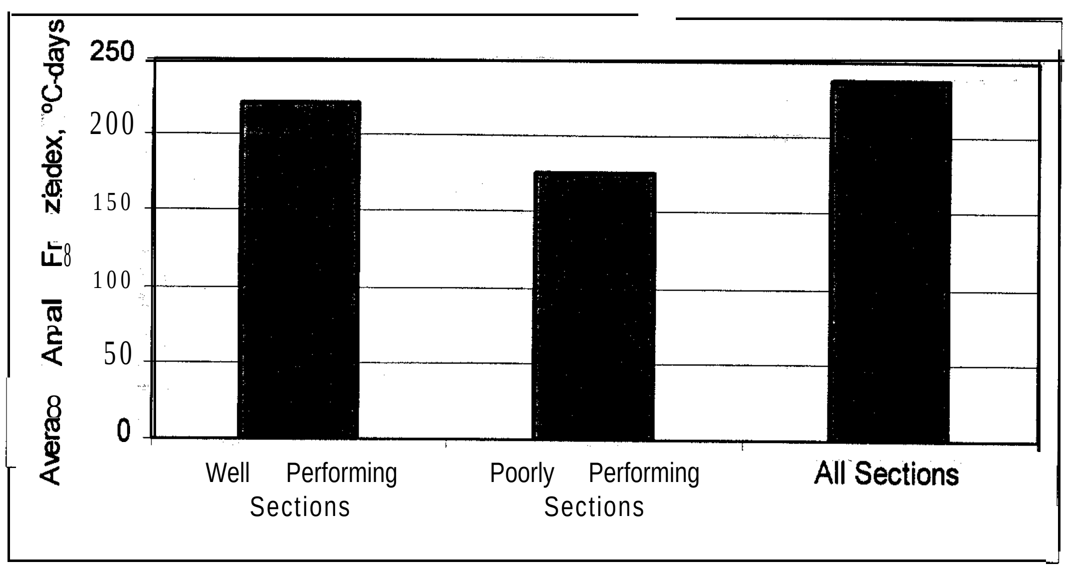

Figure 40. Comparison of annual air freeze index.

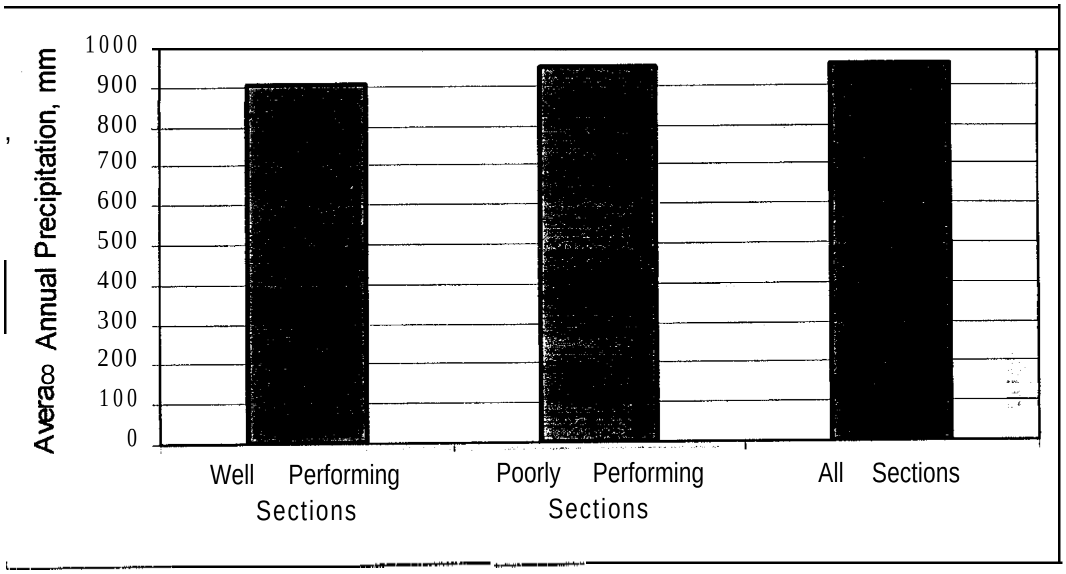

Figure 41. Comparison of annual precipitation.

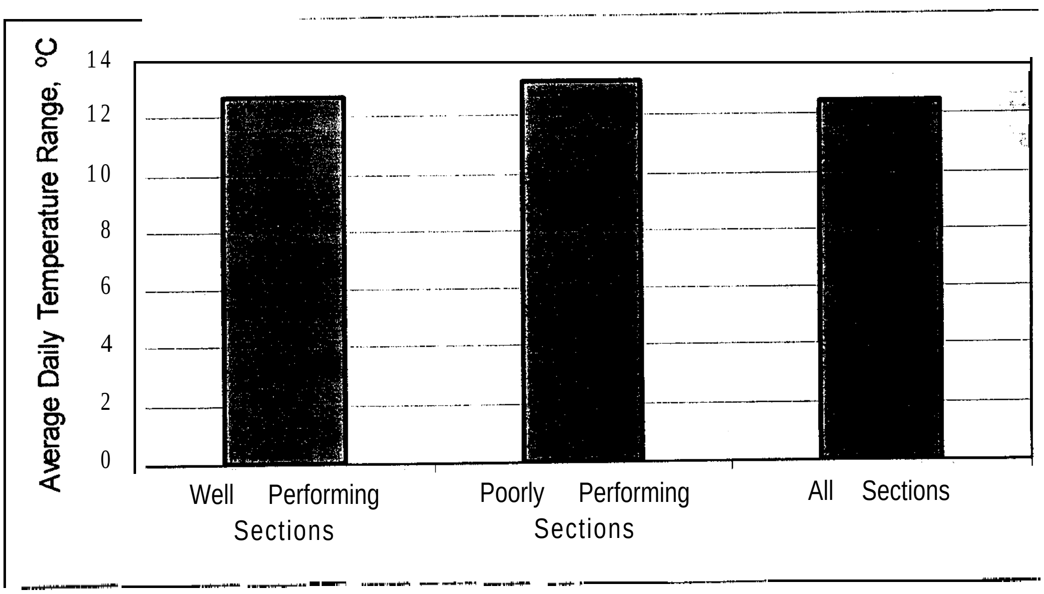

Figure 42. Comparison of daily temperature range.

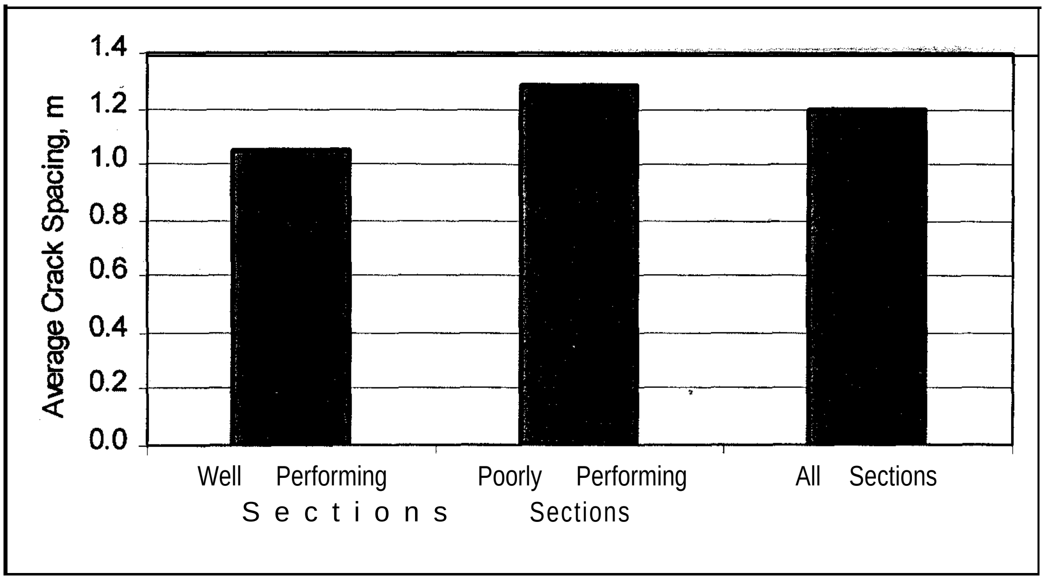

Figure 43. Comparison of crack spacing.

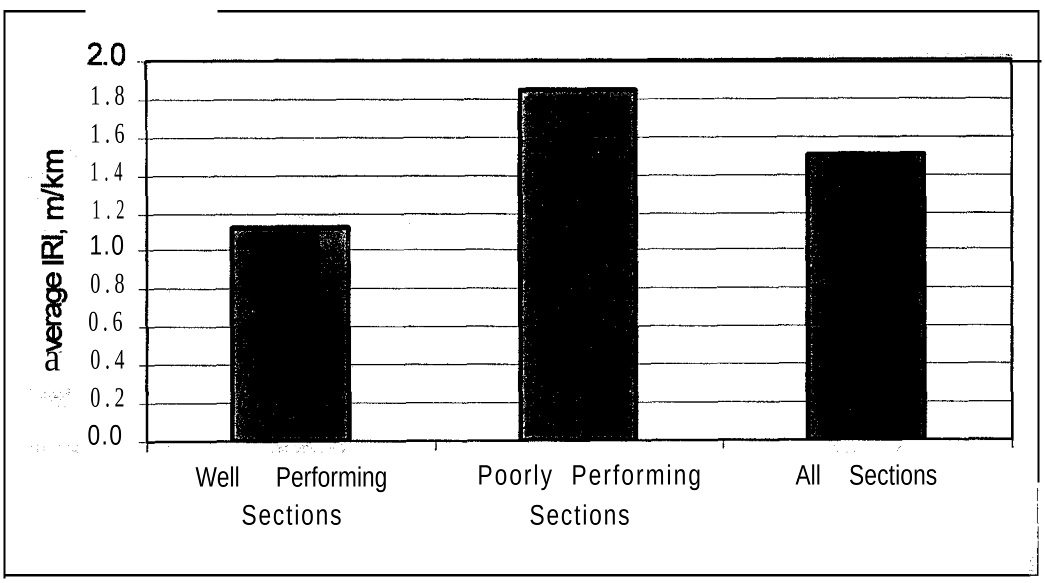

Figure 44. Comparison of IRI values.

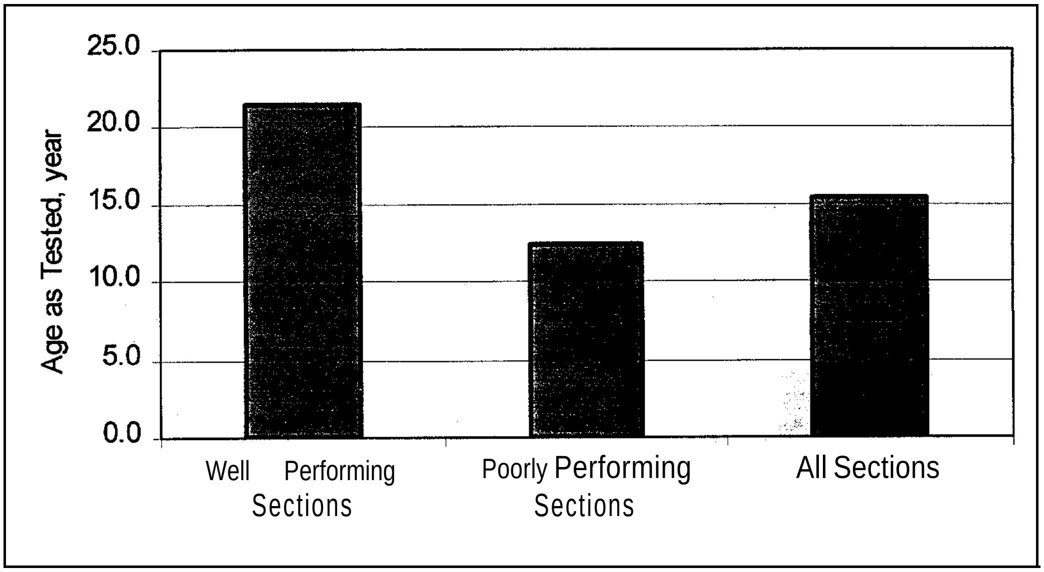

Figure 45. Comparison of age.

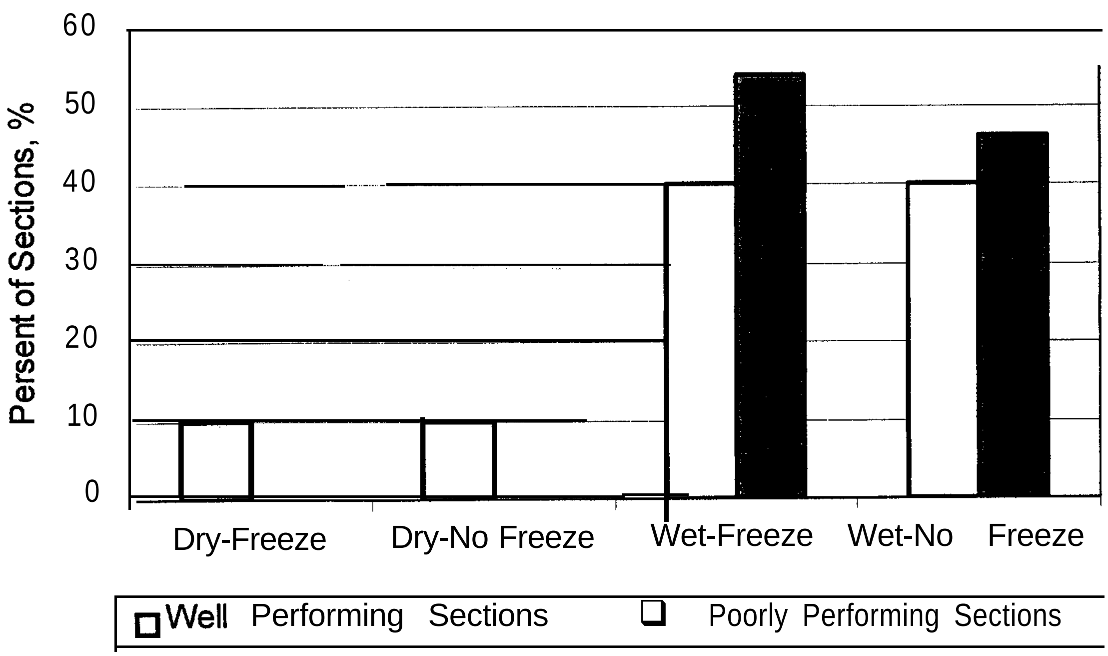

Figure 46. Effect of climatic region.

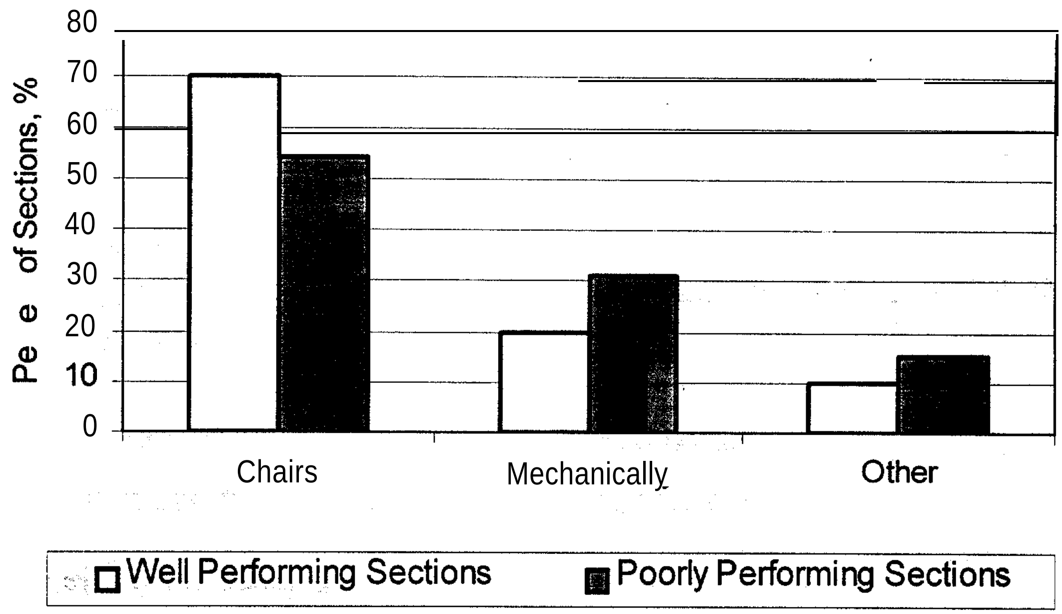

Figure 47. Effect of reinforcement placement type.

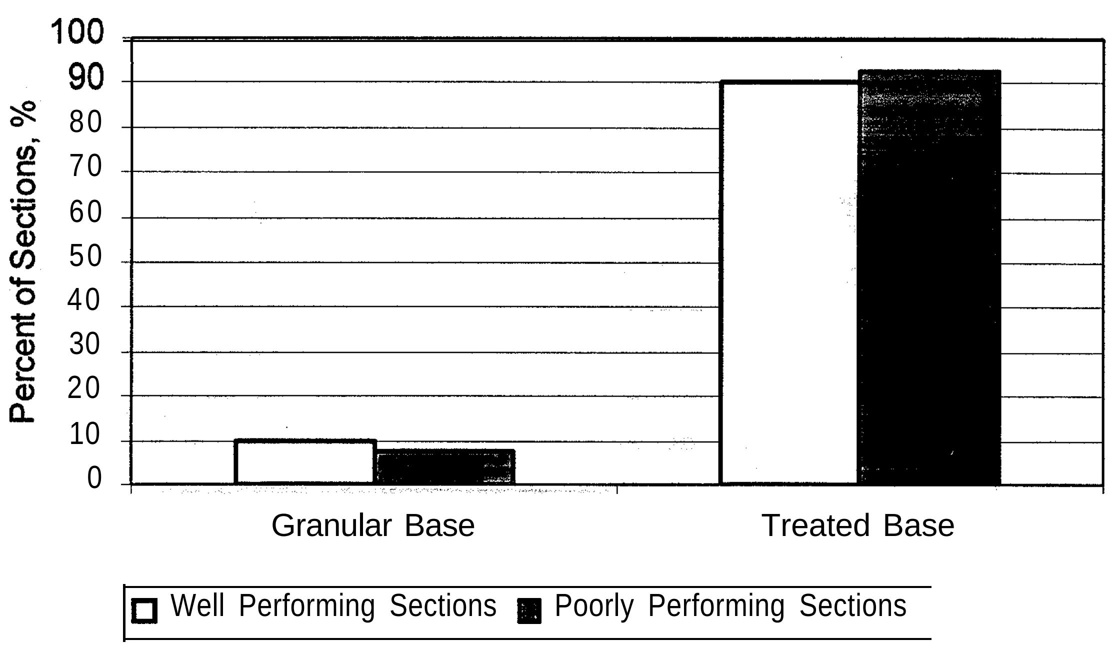

Figure 48. Effect of base type.

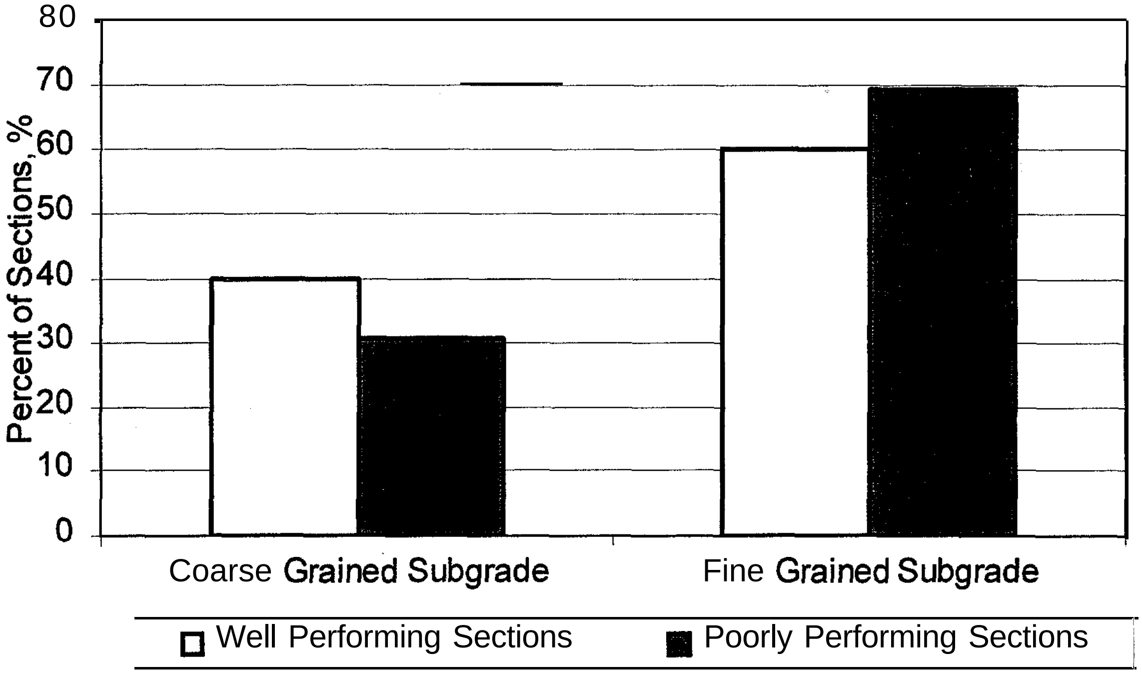

Figure 49. Effect of subgrade type.

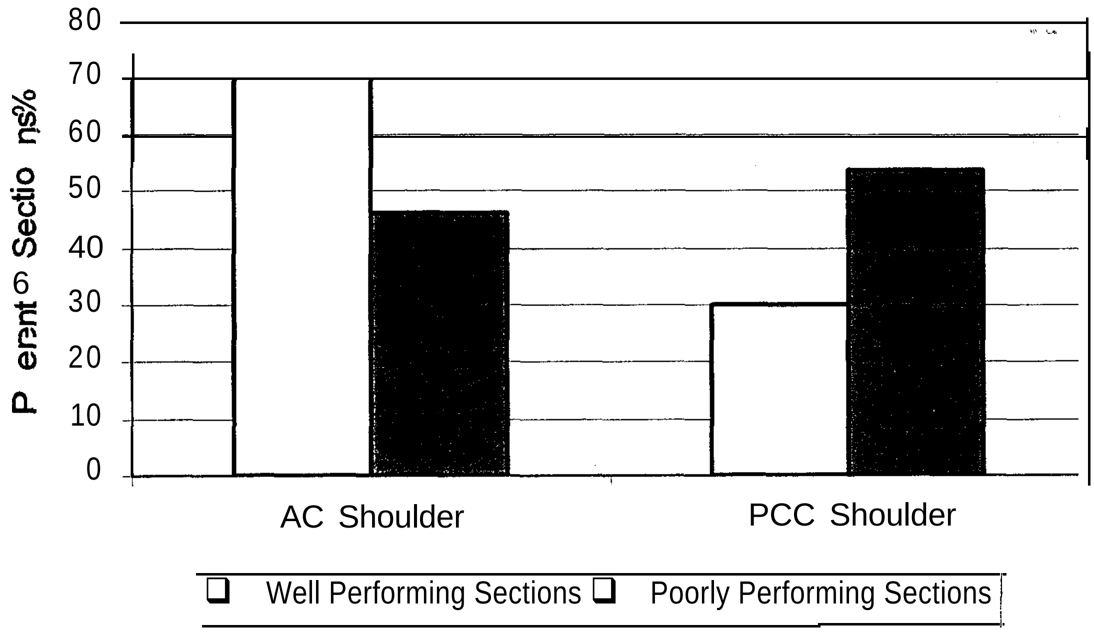

Figure 50. Effect of shoulder type.

This indicates that for the GPS-5 sample analyzed, the sections with relatively thinner concrete slabs and stiffer concrete may result in better performance. The observation related to slab thickness appears to contradict expectations. This may possibly be due to the confounding effects of traffic loading.

Summary

Although the statistical analysis was inconclusive overall, there is evidence among poorly performing sections that have developed high-severity cracking and punchouts early in their service life that these sections also had the following common characteristics:

- Larger crack spacing.
- Greater depth to reinforcement.
- High value of mean slab thickness.
- Low values of elastic moduli for slab and base layer.
- Low k-value for subgrade.

Similarly, well performing sections appear to have the following common characteristics:

- Smaller crack spacing.
- Lower IRI (selection criteria).
- Shallow depth to reinforcement.
- Thinner and stronger slab.
- Stiffer base and subgrade layers.

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

The study reported here was conducted to determine if currently available data from the LTPP GPS-5 experiment can be used to understand the development of crack spacing in CRC pavements and to analyze the effect of crack spacing and other design and site parameters on CRC pavement performance. The report has presented the characteristics of the GPS-5 data and has presented the results of various analyses conducted to identify the key factors that affect the performance of CRC pavements.

Overall, the study has not resulted in any conclusive findings on cause and effect relationships between key design and site parameters and performance attributes. As indicated previously, there exist several major constraints for performing conclusive analysis of performance of CRC pavements. These constraints include the following:

1. Lack of data on ambient weather conditions during the first few days after concrete placement.

2. Lack of reliable traffic loading data for each test section from the day of opening to traffic.

3. Lack of individual crack spacing data and distress maps.

4. Lack of data on concrete coefficient of thermal expansion and crack width.

5. Lack of significant distresses at the test sections. Very few sections exhibited localized failures and high-severity cracking. Also, most of the sections that were overlaid did not exhibit localized failure or poor ride. Thus, it is difficult to relate failure of the overlaid sections to specific attributes of the test sections.

6. Previous studies have indicated that there is a strong relationship between crack spacing, concrete strength, and percent steel. No such relationship was apparent for the GPS-5 sections. It is very likely that this is due to the biased sampling with respect to slab thickness and percent of steel used.

The analysis of the "exceptionally" well and poorly performing test sections also failed to provide definitive information regarding long-term performance of CRC pavements, although some general observations could be identified.

Previous analysis and data presented in the report have indicated that CRC pavements generally provide a good ride even after many years of service. The ride, as measured by the IRI, was generally smooth (IRI less than 1.5, typically) for most of the GPS-5 test sections.

Previous studies have also indicated that development of early crack cracking patterns in CRC pavements is significantly affected by ambient weather conditions at the time of construction. As such, design variables such as percent steel reinforcement, concrete strength, and subbase type appear to be secondary in nature. These studies have also shown that long-term cracking appears to be affected by percent steel, age, traffic loading, and concrete strength. The cracking development slows (stabilizes) after about 3 to 4 years after construction.

In order to make the GPS-5 test data more useful, it is strongly recommended that future distress surveys include a survey of 5 to 8 km of the pavement of the appropriate project to identify the amount of localized failure. The 152-m lengths of the GPS-5 test sections are considered too small to provide reliable data on localized failures.

CRC pavements have the potential to provide long-term low-maintenance service life as evidenced by the many well performing sections in the GPS-5 experiment. It is expected that as additional data become available, it will be possible to identify the specific factors and mechanisms that affect the performance of CRC pavement. This will allow improvements in the design and construction practices for CRC pavement.

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